

Biopolyester

Beyond sustainability into regeneration

Vanessa Song

Biopolyester: Beyond Sustainability into Regeneration is a study focused on redefining the fashion industry's supply chain, transitioning from a take-make-dispose linear model to a reuse-remake-revive circular model, effectively taking into consideration product's end-of-life. By fusing design, material science, and circular principles, the research explores the potential of kombucha bacterial cellulose as a replacement of polyester in support of a circular fashion economy. The study questions the importance of traditionally used ingredients, such as table sugar, tea, scoby, and apple cider vinegar, in the making of kombucha material (commonly referred to as 'kombucha leather'). Instead, experiments assess the potential of wheat starch-derived glucose and a resource-conserving recipe, producing a visually pleasing and robust material. The grown material is then transformed into threads and woven into a garment, highlighting its potential for textile applications. The research underscores the pressing necessity to move beyond sustainability towards adopting a regenerative approach.

With a shared interest in regenerative biomaterials, Vanessa Song joined the Materiability Research Group as a researcher in residency in March 2024. Building on the fully bio-based kombucha threads she developed during her master's thesis, her following research delves into the integration of kombucha threads to create a hybrid textile fabric. This involves assessing the collective influence of weaving techniques and material combinations on textural behavior.



ISBN 978-1-988366-72-2



Riverside Architectural Press

LIVING ARCHITECTURE SYSTEMS GROUP

Biopolyester

Beyond sustainability into regeneration

Vanessa Song



MATERIABILITY
RESEARCH GROUP

LASG



LIVING ARCHITECTURE SYSTEMS GROUP

Biopolyester

Beyond sustainability into regeneration

Vanessa Song



MATERIALITY
RESEARCH GROUP



Publisher: Riverside Architectural Press, www.riversidearchitecturalpress.ca
© Living Architecture Systems Group and Riverside Architectural Press 2025

Title: Biopolyester: Beyond Sustainability into Regeneration / Vanessa Song.
Names: Song, Vanessa, author.
Living Architecture Systems Group, issuing body.

Description: Edited by Manuel Kretzer and Virginia Binsch. | Includes bibliographical references.

Identifiers: Canadiana 20250195380 | ISBN 9781988366722 (PDF)

Subjects: LCSH: Fashion design—Environmental aspects. | LCSH: Textile industry—Environmental aspects. | LCSH: Circular economy. | LCSH: Sustainable design.

Classification: LCC TT497 .S66 2025 | DDC 746.9/2—dc23

Design and Production: Vanessa Song, Manuel Kretzer, Virginia Binsch, Philip Beesley, Adrian Chiu



All rights reserved.

The individual authors shown herein are solely responsible for their content appearing within this publication. CC BY-NC-SA: This license allows reusers to distribute, remix, adapt, and build upon the material in any medium or format for noncommercial purposes only, and only so long as attribution is given to the creator. If you remix, adapt, or build upon the material, you must license the modified material under identical terms. Errors or omissions will be corrected in subsequent editions.

This book is set in Garamond, Swis721 BT and Zurich BT.



Contents

4	Introduction
8	Literature Review
18	Material Development
66	Material Applications
67	Woven Kombucha Dress
78	Woven Hybrid Corset
122	Conclusion
123	Afterword
124	About Collaboration
126	References



Introduction

How can bio-based polyester support a truly circular fashion economy?

Biopolyester: Beyond Sustainability into Regeneration is a study focused on reshaping the fashion supply chain towards more conscientious production and consumption. Rooted in a profound appreciation for craftsmanship and the storytelling power of fashion, this research bridges the gap between mindful consumption and the diminishing presence of skilled artisans in an industry dominated by fast fashion. Fashion serves as a platform for personal expression and creativity, extending beyond mass production, yet only a handful of brands prioritize quality and distinctive narratives.

Polyester stands out as the most widely produced and sourced fabric in the fashion sector,¹ despite its substantial environmental impact across its lifecycle, encompassing carbon emissions, pollution, microplastic release, and landfill accumulation.² Yet synthetic fibers are forecasted to comprise 98% of all future fibers, with 95% expected to be polyester. By fusing design, material science, and circular principles, the research aims to develop a regenerative material as a replacement for petroleum-based polyester.

By focusing on the material composition of our clothes, we are targeting the problem at its core, addressing concerns of microplastic release, carbon emissions, pollution, and landfill accumulation. This is a step towards ensuring the longevity of fashion as a creative medium for future generations.

1 Textile Exchange. (n.d.). *Preferred Fiber and Materials Market Report 2022 (2024a, September 26)*. <https://textileexchange.org/knowledge-center/reports/materials-market-report-2022/>

2 European Parliament. (n.d.). *The impact of textile production and waste on the environment (infographics) | Topics*. <https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics>

3 Chen, X., Memon, H. A., Wang, Y., Marriam, I., & Tebyetekerwa, M. (2021). Circular economy and sustainability of the clothing and textile industry. *Materials Circular Economy*, 3(1). <https://doi.org/10.1007/s42824-021-00026-2>

4 Makarov, I. S., Golova, L. K., Vinogradov, M. I., Levin, I. S., Gromovykh, T. I., Arkharova, N. A., & Kulichikhin, V. G. (2019). Cellulose Fibers from Solutions of Bacterial Cellulose in N-Methylmorpholine N-Oxide. *Fibre Chemistry*, 51(3), 175-181. <https://doi.org/10.1007/s10692-019-10069-6>

5 Tapias, Y. a. R., Di Monte, M. V., Peltzer, M. A., & Salvay, A. G. (2021b). Bacterial cellulose films production by Kombucha symbiotic community cultured on different herbal infusions. *Food Chemistry*, 372, 131346. <https://doi.org/10.1016/j.foodchem.2021.131346>

6 Rykkelid, E. (2015, April 18). *Growing products*. Tumblr. <https://growingproducts.tumblr.com/post/116720734816/growing-experimentation-i-started-growing>

Kombucha Bacterial Cellulose

Bacterial cellulose, an extensively studied resource, holds remarkable properties including excellent permeability, high purity, and high mechanical strength.⁴ Kombucha, an accessible form of bacterial cellulose, employs bacteria and yeast in fermenting a brew (traditionally black tea, sucrose, kombucha starter liquid, SCOBY, and apple cider vinegar) to produce a biofilm over the surface of the brew.⁵

The research explores the potential of kombucha bacterial cellulose to develop a biodegradable textile thread. Experiments assess a resource-conserving recipe,⁶ questioning the importance of traditionally used ingredients such as sucrose, black tea, apple cider vinegar, and SCOBY in the production of a strong material. Wheat starch-derived glucose replaces sucrose, aiming to broaden sourcing options and ultimately repurpose pasta wastewater, an abundant food waste byproduct.

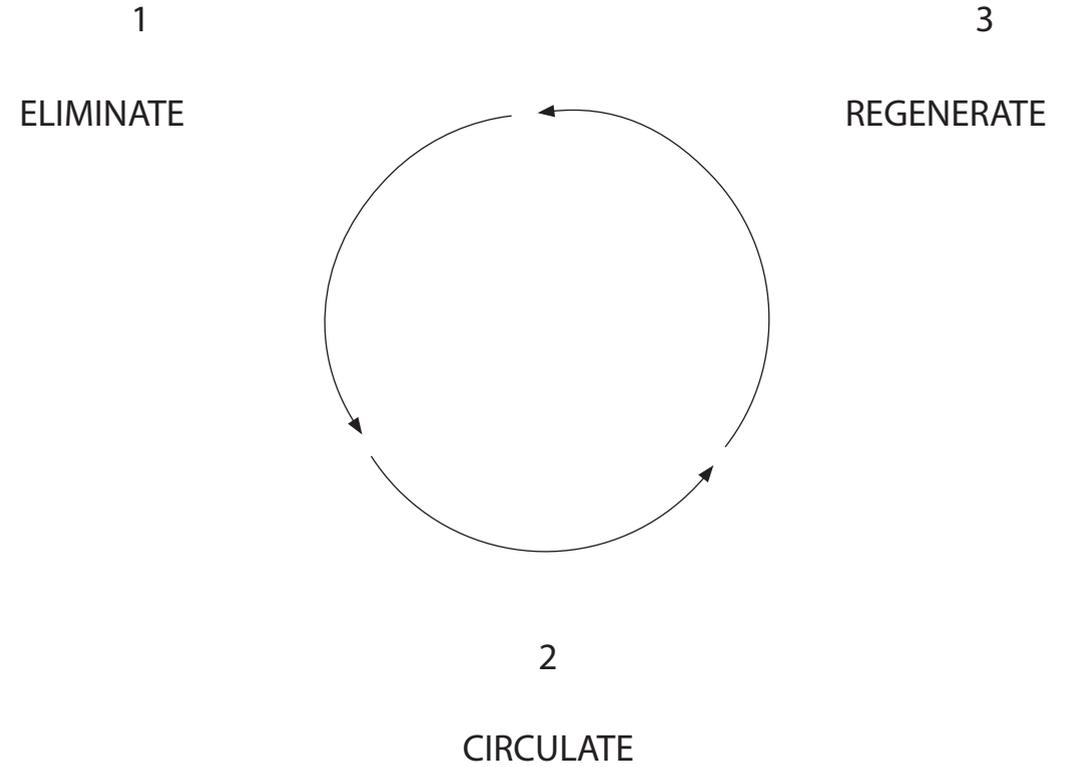
Circular Model of Design

By regenerative material, this means being 100% bio-based, 100% biodegradable, and sourced from locally abundant biomass that is otherwise underutilized.⁷ It is the sole use of bio-based materials, such as kombucha and wheat starch, throughout the entire process that helps ensure complete product biodegradability at its end of life. Exploring wheat starch as a food source not only helps to diversify sourcing beyond traditional sucrose, but also presents an opportunity to repurpose food waste, such as pasta wastewater for a closed loop system.

⁷ Materiom. (n.d.). *What do we mean by "regenerative" materials?* <https://resources.materiom.org/article/what-do-we-mean-by-regenerative-materials/>

This circular approach fosters an integrated horizontal supply chain—a collaboration between the food service and fashion industries—encouraging a shared systemic commitment towards circular practices. By moving beyond sustainability into regeneration, we are referring to a goal that is not merely to minimize environmental impact, but to create materials that revive and give back to the environment, in hope of establishing a fashion economy built on circularity—where materials and products circulate for as long as possible, waste eliminates, and pollution vanishes.⁸

⁸ Ellen MacArthur Foundation. (n.d.). *How to build a circular economy.* <https://www.ellenmacarthurfoundation.org/>



Take-make-dispose
(Linear model)



Reuse-remake-revive
(Circular model)

Literature Review

The literature review explores the environmental challenges posed by the global fashion industry's growth, with a focus on the impact of polyester production and fast fashion. It examines the rise of sustainability initiatives, including the use of natural and recycled fibers, and highlights the transition towards circular fashion practices. Additionally, it discusses advancements in bio-based materials and recycling technologies as potential solutions to reduce the industry's ecological footprint. This review underscores the need for systemic changes in material sourcing, production, and consumption to foster long-term circularity in fashion.

9 Oberlo. (n.d.). *Apparel Industry Statistics (2018-2028)*. <https://www.oberlo.com/statistics/apparel-industry-statistics>

10 Kwon, T. A., Choo, H. J., & Kim, Y. (2019). Why do we feel bored with our clothing and where does it end up? *International Journal of Consumer Studies*, 44(1), 1-13. <https://doi.org/10.1111/ijcs.12540>

11 United Nations Climate Change. (2018, January 22). Fashion Industry, UN Pursue Climate Action for Sustainable Development. *UNFCCC.int*. <https://unfccc.int/news/fashion-industry-un-pursue-climate-action-for-sustainable-development>

12 Chen, X., Memon, H. A., Wang, Y., Marriam, I., & Tebyetekerwa, M. (2021b). Circular economy and sustainability of the clothing and textile industry. *Materials Circular Economy*, 3(1). <https://doi.org/10.1007/s42824-021-00026-2>

13 Stanton, A. (2025, April 10). *What is fast fashion, anyway?* The Good Trade. <https://www.thegoodtrade.com/features/what-is-fast-fashion/>

14 Cernansky, R. (2021, October 18). Why destroying products is still an "Everest of a problem" for fashion. *Vogue Business*. <https://www.voguebusiness.com/sustainability/why-destroying-products-is-still-an-everest-of-a-problem-for-fashion>

The Fashion Dilemma

In recent years, the global apparel industry has experienced exponential growth, with anticipated revenues surpassing \$1.7 trillion by 2023,⁹ driven by fast fashion and changing consumer trends.¹⁰ However, this growth comes at a significant environmental cost. The industry is a major contributor to pollution, carbon emissions, and textile waste, with petroleum-based polyester being a central culprit.¹¹

Consumers' insatiable appetite for novelty and changing trends exacerbates the problem, leading to excessive consumption and disposal of clothing after minimal use.¹² Fast fashion companies, fueled by social media and aggressive marketing tactics, perpetuate this cycle by producing cheap, low-quality garments at an unprecedented rate.¹³

Excessive production often results in unsold stock, which is commonly burned to maintain brand exclusivity and avoid devaluing products.¹⁴ Furthermore, a knowledge gap exists between sellers and buyers, with many companies engaging in greenwashing to portray polyester as more eco-friendly than it truly is. These challenges underscore the urgent need for the fashion industry to adopt circular practices and prioritize circularity over profit.

Polyester, the Synthetic Fiber

Polyester, synthesized from coal, petroleum, air, and water through a condensation reaction, boasts thermoplastic properties facilitating both production and recycling.¹⁵ Its chemical composition, predominantly ester and terephthalic acid, endows it with strength, low shrinkage, and resistance, enabling a diverse array of fabric textures.¹⁶ However, its durability and non-biodegradability pose environmental hazards, persisting in landfills for centuries and shedding microplastics into marine habitats.¹⁷

Polyester production's heavy reliance on oil exacerbates pollution, with wet processing stages contributing to significant energy consumption and carbon emissions.¹⁸ Despite environmental concerns, polyester remains dominant in global fiber production,¹⁹ prized for its easy care, wrinkle resistance, cost-effectiveness, and durability, reinforcing its pervasive presence in the fashion and textiles industry.

15 ScienceDirect Topics. (2014). Polyester Fiber - an overview. *Sciencedirect.com*. <https://www.sciencedirect.com/topics/chemistry/polyester-fiber>

16 The Versatility and Comfort of Cotton Polyester Blend Fabric. (n.d.). *Langka*. Retrieved January 2, 2024, from <https://langka.group/blogs/langka-blogs/the-versatility-and-comfort-of-cotton-polyester-blend-fabric>

17 Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*, 112(1-2), 39-45. <https://doi.org/10.1016/j.marpolbul.2016.09.025>

18 Zhang, S., Xu, C., Xie, R., Yu, H., Sun, M., & Li, F. (2022). Environmental assessment of fabric wet processing from gate-to-gate perspective: Comparative study of weaving and materials. *The Science of the Total Environment*, 857, 159495. <https://doi.org/10.1016/j.scitotenv.2022.159495>

19 Textile Exchange. (n.d.). *Preferred Fiber and Materials Market Report 2022 (2024a, September 26)*. <https://textileexchange.org/knowledge-center/reports/materials-market-report-2022/>

The Sustainability Approach

In response to environmental concerns surrounding conventional polyester, the fashion industry has seen a surge in sustainability initiatives.

Natural fibers, notably cotton, emerge as biodegradable alternatives, though challenged by water-intensive cultivation and pesticide use.²⁰ Organic cotton offers reduced environmental impact but faces challenges in scalability.²¹ Other synthetic fibers like polyamide, polypropylene, acrylic, and elastane offer specific functionalities but pose similar environmental issues to polyester.

Recycled polyester presents a significant alternative, sourced from discarded plastic bottles and textile waste, showcasing potential for circularity. Initiatives like the 2025 Recycled Polyester Challenge and collaborations between brands and environmental organizations aim to increase its adoption and reduce greenhouse gas emissions.²²

Advanced recycling technologies like Teijin's PU elastomer fiber removal²³ and the use of hartshorn salt for polyester-cotton blend separation²⁴ offer innovative solutions to enhance the quality of recycled materials. Mechanical, chemical, and biological recycling methods aim to address challenges in fiber separation and quality degradation, yet face obstacles in scalability and environmental impact.²⁵

Furthermore, brands like Adidas, Stella McCartney, and Patagonia lead the charge in incorporating recycled polyester into their products, driving awareness and action towards sustainable fashion. Retail initiatives like Looop²⁶ and fiber innovations like Nucycl²⁷ and Repetable²⁸ offer diverse options for recycled polyester, though challenges in microplastic shedding and biodegradability persist.

20 United Nations Environment Programme. (n.d.). *Cleaning up couture: what's in your jeans?* UNEP <https://www.unep.org/news-and-stories/story/cleaning-couture-whats-your-jeans>

21 ARMEDANGELS. (n.d.). *We are here to make a Change, not Fashion*. <https://www.armedangels.com/>

22 Textile Exchange. (n.d.). *Preferred Fiber and Materials Market Report 2022 (2024a, September 26)*. <https://textileexchange.org/knowledge-center/reports/materials-market-report-2022/>

23 Teijin (2023). *Teijin Frontier Facilitates Recycling of Discarded Polyester Apparel with Novel Technology for Removing Polyurethane Elastomer Fiber*. https://www.teijin.com/news/2023/04/10/20230410_01.pdf

24 Team, C. (2023, August 7). *Hartshorn salt and "baking" solves a serious environmental problem*. <https://science.ku.dk/english/press/news/2023/hartshorn-salt-and-baking-solves-a-serious-environmental-problem/>

25 Everra. (2025, March 5). *Global Fiber Supply Chain Solutions | Reliable & Sustainable*. <https://steinfibers.com/environment/>

Despite these advancements, a comprehensive approach addressing consumption habits, supply chain practices, and material selections is essential for substantial industry change. Collaboration and integration among various sustainability methods are key to achieving lasting transformation in the fashion industry.

26 HM (n.d.) *Recycling System 'Loop' Helps H&M Transform Unwanted Garments into New Fashion Favourites*. <https://about.hm.com/news/general-news-2020/recycling-system-loop-helps-h-m-transform-unwanted-garments-i.html>

27 Evnu. (n.d.). *Nucycl® by Evnu*. <https://www.evnu.com/nucycl>

28 RadiciGroup. (n.d.). *Polyamide PA6 textile yarn, Repetable®*. <https://www.radicigroup.com/en/products/fibres-and-nw/repetable>

29 Materiom. (n.d.-a). *Materiom*. <https://materiom.org/>

30 MUD Jeans. (n.d.). *Lease a jeans*. <https://mudjeans.de/pages/lease-a-jeans>

31 The Reformation. (n.d.). *RefRecycling | Clothing & Shoe recycling*. <https://www.thereformation.com/sustainability/ref-recycling.html>

32 The North Face (2022). *The North Face Renewed Take-Back*. Retrieved January 2, 2024, from <https://www.thenorthface.com/en-ca/approach/the-north-face-renewed-take-back>

Advancing Circular Fashion

In response to the limitations of short-term sustainability initiatives, a noteworthy shift towards circularity has emerged in the fashion industry. Central to this concept lies a commitment to eliminating environmental impact at every stage through conscientious production and consumption. This involves considering every facet of a garment's life cycle, spanning from production to eventual disposal, reflecting a systemic approach that redefines how clothes circulate within the economy. This requires a shift in design philosophy towards comprehensive end-of-life strategies.

The Ellen MacArthur Foundation leads this change by advocating for waste elimination, material longevity, and natural system regeneration. Materiom supports this by providing open-source recipes for regenerative materials.²⁹ Embracing these ideals are brands starting to actively participate in take-back schemes for used garments, invest in repairable designs, and follow cradle-to-cradle principles. These initiatives directly tackle root causes, catalyzing systemic change while striving to minimize waste, extend product lifecycles, and transform consumption patterns for a more resilient fashion ecosystem.

Examples:

- Mud Jeans: Offers jeans made from recycled and organic materials, allowing consumers to lease jeans and return old pairs for recycling.³⁰
- Reformation: Uses mostly recycled or renewable materials and offers store credits for returned items, then broken down into fibers for new products.³¹
- The North Face: Provides credits for returned gear, which is inspected, repaired, resold, or recycled.³²

Role of Feedstock

Bio-based materials come from various feedstocks, ranging from first-generation (agricultural crops) to fourth-generation (advanced biotechnology sources).³³ Currently, most bio-based materials rely on first-generation sources like corn starch,³⁴ which competes with food production for land and water.³⁵ Second-generation sources, such as wood cellulose, are also used but can lead to deforestation and habitat loss.³⁶ Diversifying feedstock sources can ensure a steady supply, reduce resource depletion, and lower environmental impact by sourcing materials closer to end markets, which also cuts transportation costs and emissions.

A significant challenge lies in the lack of standardization for materials labeled as “bio-based,” as they may contain as little as 30% bio-based content. Clear terminology and greater transparency are crucial to prevent misleading consumers.

33 Esposti, M. D., Morselli, D., Fava, F., Bertin, L., Cavani, F., Viaggi, D., & Fabbri, P. (2021). The role of biotechnology in the transition from plastics to bioplastics: an opportunity to reconnect global growth with sustainability. *FEBS Open Bio*, 11(4), 967-983. <https://doi.org/10.1002/2211-5463.13119>

34 Rosenboom, J., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. *Nature Reviews Materials*, 7(2), 117-137. <https://doi.org/10.1038/s41578-021-00407-8>

35 NatureWorks. (n.d.). *Home*. <https://www.natureworkslc.com/>

36 Robertson, L. (2024, February 12). Material Guide: *What is Viscose and Is It Sustainable? - Good On You*. Good on You. <https://goodonyou.eco/material-guide-viscose-sustainability/>

37 Zhao, X., Wang, Y., Chen, X., Yu, X., Li, W., Zhang, S., Meng, X., Zhao, Z., Dong, T., Anderson, A., Aiyedun, A., Li, Y., Webb, E., Wu, Z., Kunc, V., Ragauskas, A., Ozcan, S., & Zhu, H. (2023). Sustainable bioplastics derived from renewable natural resources for food packaging. *Matter*, 6(1), 97-127. <https://doi.org/10.1016/j.matt.2022.11.006>

38 Cao, P., Wu, G., Yao, Z., Wang, Z., Li, E., Yu, S., Liu, Q., Gilbert, R. G., & Li, S. (2022). Effects of amylose and amylopectin molecular structures on starch electrospinning. *Carbohydrate Polymers*, 296, 119959. <https://doi.org/10.1016/j.carbpol.2022.119959>

39 Bioplastics Magazine. (2015). *Virent BioformPX paraxylene used for world's first 100% plant-based pet plastic bottle*. <https://www.bioplasticsmagazine.com/en/news/meldungen/20150608Virent-at-basis-of-biosourced-PlantBottle.php>

40 Dornbirm GFC. (n.d.). *Home*. <https://www.dornbirm-gfc.com/de/>

41 Textile Exchange. (n.d.). *Preferred Fiber and Materials Market Report 2022 (2024a, September 26)*. <https://textileexchange.org/knowledge-center/reports/materials-market-report-2022/>

42 OceanSafe. (n.d.). *Circular Textile Technology | NANEA*. <https://www.oceansafe.co/textile-materials/nanea>

43 Dove, S. (2011, September 28). China losing its factory of the world to Bangladesh? *Ecotextile News*. <https://www.ecotextile.com/2023052530735/materials-production-news/bio-based-synthetic-fibres-did-not-degrade.html#%E2%80%8C>

44 Common Objective. (2018). *Viscose And Its Impact*. <https://www.commonobjective.co/article/viscose-and-its-impact>

First-generation feedstock include plant sugars and vegetable oils, used to produce polyesters like PLA, PBS, and PEF.³⁷ Corn starch, due to its abundance and cost efficiency, is the most common source. However, impurities in starch can affect polyester quality, and high amylopectin content is necessary for effective polymerization.³⁸

Examples of Innovations:

- BioFormPX® Paraxylene: Derived from sugar beet plants, used to create 100% plant-based polyester.³⁹
- NOOSA®: GMO-free fiber from corn, completely recyclable and eco-friendly.⁴⁰
- Ecodear® PET: Made from sugarcane-derived ethylene glycol sources.⁴¹
- OceanSafe naNea: Biodegradable PET fibers meeting Cradle to Cradle Certified® Gold standard.⁴²

However, a study revealed that some bio-based polyesters like PLA do not biodegrade in marine environments, contrary to their claims.⁴³ This underscores the need for standardized tests to validate biodegradability.

Second-generation feedstock include plant cellulose and agricultural residues. Cellulose, a renewable and biodegradable polymer, requires chemical processing to be used in textiles. Examples include viscose, which, despite being renewable, can have severe environmental impacts due to chemical-intensive production processes.⁴⁴

Examples of Sustainable Viscose:

- NAIA™ Renew: Made from wood pulp and recycled waste, certified for biodegradability.⁴⁵
- Livaeco Viscose: Sourced from FSC®-certified forests and biodegradable.⁴⁶

Third-generation feedstock are derived from microorganisms like algae, bacteria, and yeast, these sources do not compete with food production.⁴⁷ Bacterial cellulose (BC), for example, offers high-quality and pure bio-based polyesters but faces production cost challenges.⁴⁸

Examples of Bacterial Cellulose:

- Nullarbor: Microbial cellulose from waste materials, used in textile production.⁴⁹
- Nanocellulose by Modern Synthesis: Combines microbial growth and textile production for durable materials.⁵⁰
- Kombucha Bacterial Cellulose (KBC): Cultivated from fermented tea, this method faces issues like color and odor, requiring purification.⁵¹

Kombucha Leather Innovations:

- Suzanne Lee: Develops sustainable biomaterial textiles using kombucha fermentation.⁵²
- Ellen Rykkelid: Explores various nutritional sources for cultivating bacterial cellulose without traditional kombucha ingredients.⁵³
- Nadia Elkady: Investigates BC composites to improve aesthetics and texture for the leather industry.⁵⁴
- Sacha Laurin: Creates kombucha jewelry and couture.⁵⁵

In conclusion, addressing the challenges of polyester consumption requires diverse strategies and innovative approaches to sourcing and production. A circular approach, focusing on material transformation, extending garment life, and minimizing waste, is essential for circular fashion. The success of these initiatives hinges on behavioral changes, infrastructure adaptations, and sustainable sourcing practices to avoid deforestation and maintain ecological balance.

45 Eastman. (n.d.). *Naia from Eastman | Cellulosic Yarn | Sustainable Fiber*. <https://naia.eastman.com/>

46 Birla Cellulose. (n.d.). *Birla Cellulose | A trusted name in Viscose Staple Fibre, MMF*. <https://birlacellulose.com/>

47 Lackner, M. (2022). Third-Generation biofuels: bacteria and algae for better yield and sustainability. In *Springer eBooks* (pp. 1947-1986). https://doi.org/10.1007/978-3-030-72579-2_90

48 Popa, L., Ghica, M. V., Tudoroiu, E., Ionescu, D., & Dinu-Pirvu, C. (2022). Bacterial Cellulose—A remarkable polymer as a source for biomaterials tailoring. *Materials*, 15(3), 1054. <https://doi.org/10.3390/ma15031054>

49 Nanollose. (n.d.). *Nullarbor*. <https://nanollose.com/products/nullarbor/>

50 Modern synthesis. (n.d.). <https://www.modernsynthesis.com/legal#faqs>

51 Kołodziejczyk, A. (2021). Bacterial cellulose: multipurpose biodegradable robust nanomaterial. In *IntechOpen eBooks*. <https://doi.org/10.5772/intechopen.98880>

52 Fashioning Circuits. (2014, March 18). *Sustainable fashion: Kombucha as Couture*. <https://fashioningcircuits.com/?p=2127>

53 Rykkelid, E. (2015, April 18). *Growing products*. Tumblr. <https://growingproducts.tumblr.com/post/1116720734816/growing-experimentation-i-started-growing>

54 Elkady, N. (2021). *Microbial Leather: The Feasibility of Bacterial Cellulose Composites as Alternative Bio-textiles* (Master's thesis). Hochschule Anhalt, Germany.

55 Sacha Laurin. (n.d.). *Kombucha Couture*. <http://www.kombuchacouture.com/>

Area of Focus: Advancing Beyond Plant Cellulose

Enhancing Material Properties with Bacterial Cellulose

Traditional cellulose from wood, like in viscose production, requires extensive treatment with harmful chemicals and lacks mechanical strength due to impurities like lignin. Bacterial cellulose offers superior mechanical properties and a cleaner production process, making it a promising alternative.

Tackling Biodegradability Challenges

Synthetic fibers shed from clothing during washing accumulate in aquatic environments, posing environmental hazards due to their resistance to biodegradation. Nano-scale fibers are particularly problematic, as they are difficult to filter and can contaminate water sources. Utilizing bacterial cellulose from kombucha, which is cost-effective and accessible, addresses these concerns.

Fusion of Kombucha Bacterial Cellulose and Wheat Starch

An accidental discovery involving solidified pasta wastewater resembling bioplastic sparked interest in wheat starch as a core ingredient for bioplastic production. While existing research focused on corn starch, diversifying sources became essential. Combining wheat starch with bacterial cellulose offers the benefits of both approaches, leveraging starch's abundance and the high-quality bio-based polyesters from bacterial fermentation.

Material Development

This research was rooted in experimentation, emphasizing exploration and result comparison through an extensive trial-and-error approach. The primary aim was to investigate the use of wheat starch-derived glucose as an alternative carbon source in the fermentation of kombucha bacterial cellulose, comparing its effectiveness to sucrose (white sugar) by assessing the tensile strength of the resulting materials. The secondary aim focused on improving the visual appeal of kombucha material for textile applications, addressing its commonly perceived unattractive natural brown hue.



Glucose Preparation

To use wheat starch as the food source for kombucha fermentation, it was first converted into glucose through a two-step process known as starch hydrolysis, employing two enzymes: amylase and glucoamylase.

Initially, amylase broke down the starch into maltose at a constant temperature of 100 °C in approximately 33 minutes, followed by glucoamylase converting maltose into glucose at a constant temperature of 60 °C in approximately three hours. After this step, it was left at room temperature for four days. This process was conducted using an electric stove and pots filled with water, with the mixture contained in a glass beaker.

To ensure the completion of each enzymatic reaction before proceeding, iodine solution was utilized to confirm the absence of starch, while glucose test strips were employed to detect high levels of glucose concentration. A change in color to orange-yellow with the iodine solution indicated the absence of starch, while a blue-black color indicated its presence. Conversely, the glucose test strips produced a brown color for high glucose concentrations, a green color for low concentrations, and a blue-turquoise color when no glucose was present.

For all recipes, medical-grade gloves were used, and all equipment was sanitized with ethanol.



Equipment and materials used



Wheat starch measured and mixed with distilled water

Glucose Recipe (1 serving = 750ml)

Equipment	Ingredients	
Stove	Distilled water	750 ml
Stainless steel pot	Wheat starch	100 g
Large glass beaker	Amylase	1 ml
Small glass beaker	Glucoamylase	1/4 tsp
Measuring utensils	Iodine solution	
Weighing scale	Glucose test strips	
Thermometer		
Pipette		
Glass rod		

Method

1. In a large beaker, mix in 100g wheat starch and 750ml distilled water. Using a pipette, add in 1ml amylase and mix thoroughly.
2. Place the beaker in a pot of boiling water for approximately 33 minutes. With a glass rod, stir occasionally.
3. Conduct an iodine test at the 33-minute mark by transferring a small amount of mixture using a pipette into a small glass beaker along with one drop of iodine solution. Mixture should turn into an orange-yellow color.
4. Remove the beaker from heat and let the mixture cool down to 60 °C. This may take approximately 35 minutes, depending on room temperature.
5. Using a thermometer, ensure temperature of the mixture is 60 °C or below before mixing in 1/4 tsp glucoamylase. Additionally, ensure water temperature in the pot is at 60 °C or below before placing the beaker in for three hours. The water temperature can vary between 56-60 °C, but should not exceed to avoid denaturing of enzymes.
6. Stir the glucose mixture occasionally. After 3 hours, remove the beaker from heat and wrap it with cling film, to be left under room temperature for 4 days for completion.



Amylase added to wheat starch-distilled water mixture before placing in boiling water



Iodine test turned mixture orange-yellow, indicating absence of starch and prompting removal from heat



Glucoamylase stirred into mixture after it cooled below 60 °C



Beakers placed in water bath at 56-60 °C for three hours before being wrapped and stored at room temperature



Glucose Filtration

The resulting glucose mixture was filtered to remove impurities from the wheat starch. The presence of white precipitate was likely due to impurities from the wheat starch. If not filtered, these impurities might have adversely impacted the growth of kombucha bacterial cellulose.

Exploration of Different Filtration Techniques for Efficiency

Utilizing filter paper in the filtration process primarily relied on gravity, making the process very time-consuming, especially with a dense precipitate. Grade 5 Whatman qualitative filter paper was used specifically for precipitate filtration, with each sheet folded into a 16-fold fluted filter to maximize surface area for efficiency.

To expedite this filtration process, alternative methods were tested, including DIY vacuum filtration and PES syringe filters. However, these alternatives proved to be more labor-intensive, which ran counter to the goal of enhancing time efficiency.

To improve the efficiency of filter paper filtration, the strategy involved producing additional glucose batches. As the precipitate settled at the bottom, the top clear layer of glucose was decanted before proceeding with filtration.

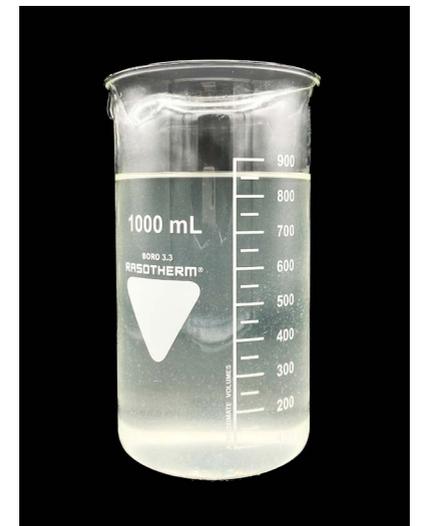


Filter paper pleated in 16-fold to maximize surface area before glucose filtration

Exploration of DIY vacuum filter and PES syringe filter to enhance efficiency



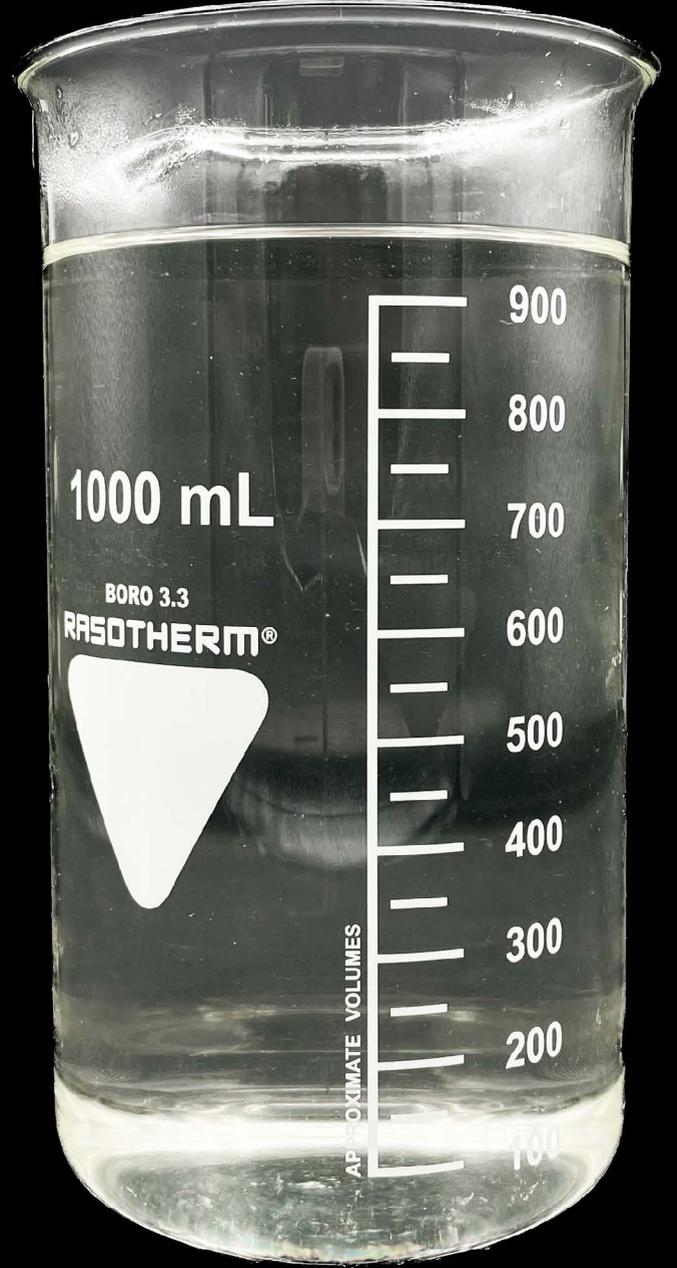
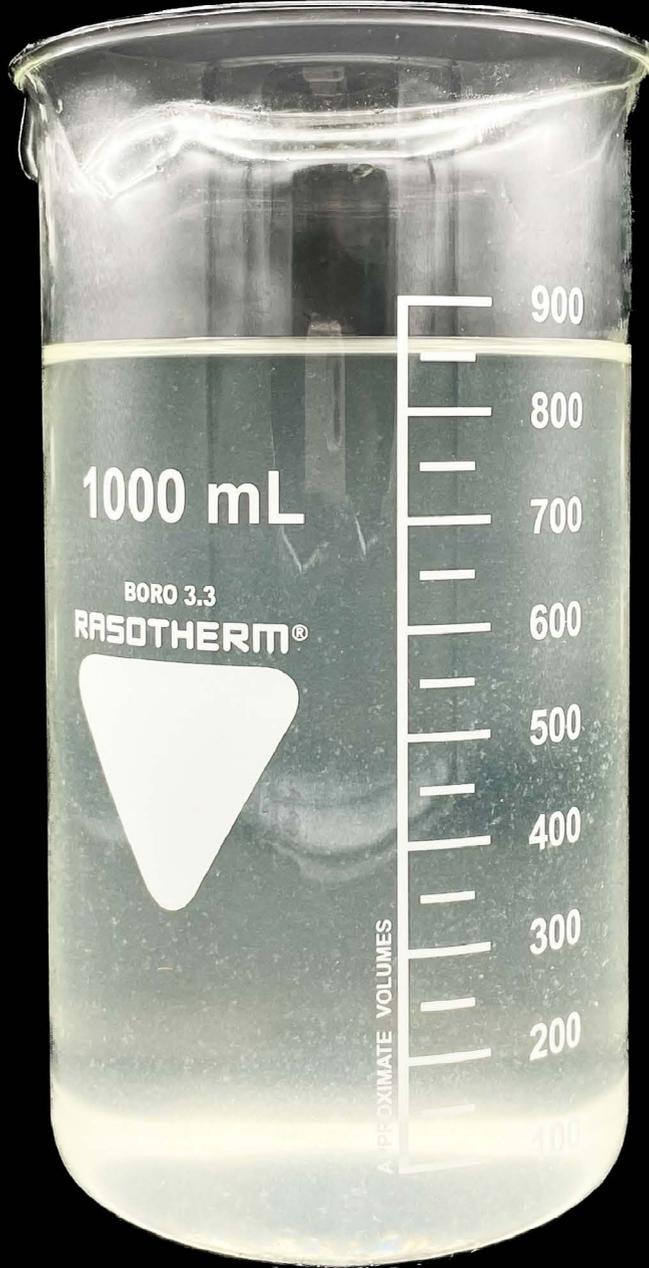
White precipitate formed at the bottom of glucose mixture



Decanting clear top layer of glucose mixture before filtration to maximize efficiency



Glucose mixture post-decant (above) and after filtration (below)



Growing Kombucha Pellicles

The process of growing the kombucha bacterial cellulose pellicles was split into three phases, each with a modified brew recipe. After preparation, each container was placed in a dark space, away from sunlight. Given the constraints of conducting the experiment during the winter semester, surrounding temperature was kept as close to 29°C as possible with heaters, heating pads or heating blankets. Containers measuring 33 cm x 20 cm x 11 cm were used.

First Phase: Sucrose, Unfiltered Glucose

The first phase utilized unfiltered glucose, meaning these samples were sourced from the clear, upper layer of glucose, containing minimal impurities.

The glucose recipe remained identical to that for 100g of wheat starch listed on page 21, with the only variation being the concentration of wheat starch, which was controlled by the amount mixed in. The first phase tested wheat starch concentrations of 100g and 250g. A control sample of 100g of white sugar was prepared for comparison to wheat starch as a potential carbon source. This control sample adhered strictly to recipe #12 from Nadia Elkady's master's thesis, *Microbial Leather*, which she identified as producing the best pellicle in terms of surface uniformity and growth rate.

Brew Recipe #1 (Sucrose)

Equipment	Ingredients	
Stove	White sugar	100 g
Stainless steel pot	Distilled water	1500 ml
Measuring utensils	Black tea bags	10 g
Thermometer	Kombucha starter liquid	25 ml
Glass rod	Apple cider vinegar	50 ml
Sieve	SCOBY	

Method

1. In a pot, boil the mixture of distilled water and sugar.
2. Weigh out 10g loose tea leaves from the tea bags. Add into the pot of boiling mixture. Bring down heat and let it simmer for approximately 10 minutes before turning the heat off. Let it cool down to 29 °C.
3. Strain the tea leaves and transfer the cooled mixture into a container. Add in apple cider vinegar, kombucha starter liquid, and a SCOBY.
4. Cover the container with a lid and seal any openings to prevent contaminants.

Brew Recipe #2 (Unfiltered Glucose)

Equipment	Ingredients	
Stove	Unfiltered glucose	750 ml
Stainless steel pot	Distilled water	750 ml
Measuring utensils	Black tea bags	10 g
Glass rod	Kombucha starter liquid	25 ml
Sieve	Apple cider vinegar	50 ml
	SCOBY	

Method

1. In a container, combine glucose, distilled water, and kombucha starter liquid. Add cooled black tea and SCOBY.
2. Mix using a glass rod. Cover the container with a lid, sealing any opening to prevent contaminants.

WHITE SUGAR
SUCROSE

DAY 1



DAY 3



DAY 8



DAY 15



100 G WHEAT STARCH
UNFILTERED GLUCOSE



250 G WHEAT STARCH
UNFILTERED GLUCOSE



First Phase Observations:

On Day 3, noticeable differences emerged between the growth of the glucose and sugar samples, with the glucose showing rapid development. A thin, dark brown layer was secreted by the SCOBY in the glucose samples.

By Day 8, the glucose samples exhibited significantly more carbonation than the sugar sample. The 100g wheat starch sample demonstrated the most promising growth rate, resulting in a relatively uniform SCOBY layer.

To encourage a more consistent SCOBY layer, efforts were made to eliminate bubbles from all samples by gently dispersing them to the edges with a sterilized spoon.

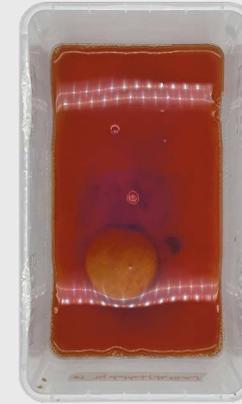
It was noted that the high glucose concentration may have contributed to excessive bubbling. Consequently, in the subsequent samples, both filtered and lower glucose concentrations (e.g., 75g) were prepared.

Second Phase: Filtered Glucose

The second phase utilized filtered glucose, building on the observations from the first phase, where 100g of wheat starch appeared to produce the most promising kombucha pellicle in terms of surface uniformity and growth rate. Therefore, the second phase tested wheat starch concentration levels of 75g, 100g, and 125g, assessing the impact of wheat starch concentration on optimal growth. Filtered glucose used were obtained through filter paper as demonstrated on page 25.

75 G WHEAT STARCH
FILTERED GLUCOSE

DAY 1



DAY 14



100 G WHEAT STARCH
FILTERED GLUCOSE

DAY 1

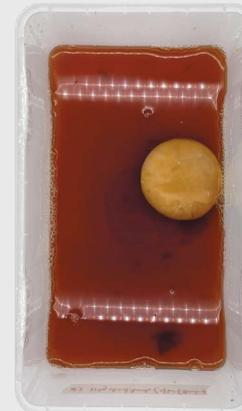


DAY 14



125 G WHEAT STARCH
FILTERED GLUCOSE

DAY 1



DAY 16



Second Phase Observations:

The results from the samples using filtered glucose did not match the anticipated outcomes. It was expected that filtered glucose would produce a thicker and more consistent pellicle than unfiltered glucose, as the latter might contain impurities that hinder growth. However, this expectation was not met.

One possible explanation for these unexpected results could be the seasonal transition from autumn to winter, which likely caused temperature fluctuations. These changes may have adversely affected the fermentation process, impacting the growth rate of the kombucha bacterial cellulose, which thrives at an optimal temperature of 29°C. Consequently, temperature became a confounding variable, distorting the true relationship reflected in the results.

Third Phase: Reduced Resources

The third phase involved testing a modified recipe based on a researcher's approach. Ellen Rykkelid, as referenced on page 16, successfully achieved uniform pellicle growth using only kombucha starter liquid, water, and a selected nutritional source, thereby eliminating the need for black tea, vinegar, and a SCOBY. The results showed a whiter, less bubbly, and more transparent pellicle upon complete drying. This advancement has the potential to reduce resource consumption and streamline the post-growth purification process, resulting in a clear, white pellicle. However, excessive sugar led to the formation of large bubbles, causing uneven pellicle growth.

For this phase, three samples were prepared with lower concentrations of 50g and 75g wheat starch alongside a control sample of 100g wheat starch. Additionally, building on the success of using grass as a nutritional source, two brews were created using pasta and rice wastewater in substitution of glucose to explore their potential. Tap water was utilized to replicate the usual water used for cooking pasta and rinsing rice in everyday scenarios.

Brew Recipe #3

(Reduced Resources: Pasta Wastewater)

Equipment	Ingredients	
Stove	Uncooked pasta	1 cup
Stainless steel pot	Tap water	1000 ml
Measuring utensils	Kombucha starter liquid	100 ml
Thermometer		
Sieve		

Method

1. Cook 1 cup of pasta using 500ml tap water.
2. Sieve the cooked pasta out and allow the wastewater to cool down to 29°C or below.
3. Into a container, add wastewater, 500ml tap water, and kombucha starter liquid. Mix with glass rod to ensure the brew is evenly mixed.
4. Cover the container with a lid and seal any openings to prevent contaminants such as maggots from entering.

Brew Recipe #4

(Reduced Resources: Rice Wastewater)

Equipment	Ingredients	
Stove	Uncooked rice	1/2 cup
Stainless steel pot	Tap water	1000 ml
Measuring utensils	Kombucha starter liquid	100 ml
Thermometer		
Sieve		

Method

1. Wash 1/2 cup of rice in 500ml tap water without rinsing it.
2. Sieve the rice out, remaining the wastewater.
3. Into a container, add wastewater, 500ml tap water, and kombucha starter liquid. Mix with glass rod to ensure the brew is evenly mixed.
4. Cover the container with a lid and seal any openings to prevent contaminants such as maggots from entering.

50 G WHEAT STARCH
FILTERED GLUCOSE

DAY 1

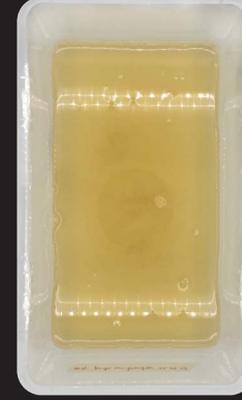


DAY 15



PASTA WASTEWATER

DAY 1



DAY 15

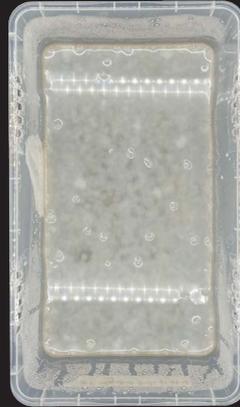


75 G WHEAT STARCH
FILTERED GLUCOSE

DAY 1

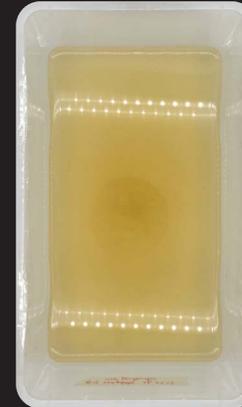


DAY 12



RICE WASTEWATER

DAY 1



DAY 15



100 G WHEAT STARCH
FILTERED GLUCOSE

DAY 1



DAY 12



Third Phase Observations:

The overall results yielded some surprising findings, especially regarding the coloration of the resulting pellicle. The batch without black tea and apple cider vinegar produced a notably lighter brew, which translated into a pellicle that is substantially lighter and whiter in color even without undergoing the purification process.

In terms of uniformity, the pellicle exhibited a consistent appearance without significant air bubbles, which can be attributed to a lower quantity of kombucha bacterial cellulose due to the absence of a SCOBY. During harvest, the pellicle felt strong and sturdy.

Regarding the use of glucose derived from wheat starch, wheat starch proved to be more promising in terms of pellicle thickness, with specifically the 75g wheat starch sample. The sample utilizing pasta and rice wastewater produced pellicles that were extremely thin and difficult to further process.



Reduced resources sample upon harvest (75g wheat starch).



Reduced resources sample upon harvest (100g wheat starch).



Reduced resources sample upon harvest (pasta wastewater).



Reduced resources sample upon harvest (rice wastewater).

Harvesting Pellicles

The pellicles obtained from the brew were harvested, and each sample's pellicle was trimmed for subsequent purification and exploration of methods to convert it into thread.

A portion of the pellicles was set aside for testing the impact of purification on tensile strength, while others were left unpurified for comparison purposes. The unpurified pellicles underwent a basic cleaning process involving washing and rinsing with dish soap to remove excess liquid and bacteria from the brew. Subsequently, they were pat-dried using paper towels and weighed to compare growth.

After harvesting, the brew remaining were retained and set aside for a subsequent round of growth to examine the potential impact of reusing the same brew on the resulting material's tensile strength.

	Sample	Weight (g)
Phase #1	100g Sugar	386.04
	100g Wheat Starch	476.80
	250g Wheat Starch	225.12
Phase #2	75g Wheat Starch	186.11
	100g Wheat Starch	102.49
	125g Wheat Starch	156.56
Phase #3	50g Wheat Starch	245.35
	75g Wheat Starch	248.51
	100g Wheat Starch	75.90



Pellicle washed with dish soap



Pellicle weighed after being washed and pat-dried



Pellicle pat-dried



Washed, pat-dried pellicle

Second Harvests

In the second harvest from the same brew, notable differences surfaced between the samples. The first and second growth phases (with black tea, SCOBY, and apple cider vinegar) produced thicker, more uniform pellicles with minimal air bubbles. In contrast, the third phase, with reduced resources, resulted in thinner pellicles during the second harvest. As noted earlier, the transition from autumn to winter likely impacted the pellicle's growth rate due to fluctuating temperatures, as reflected in the harvested pellicle weights.

The table below presents the pellicle weights for all samples, excluding the 250g and 125g wheat starch samples from phases one and two, which were discarded after deciding to explore second harvest potential.

	Sample	First Harvest Weight (g)	Second Harvest Weight (g)
Phase #1	100g Sugar	386.04	188.42
	100g Wheat Starch	476.80	242.15
	250g Wheat Starch	225.12	
Phase #2	75g Wheat Starch	186.11	429.34
	100g Wheat Starch	102.49	609.81
	125g Wheat Starch	156.56	597.85
Phase #3	50g Wheat Starch	245.35	
	75g Wheat Starch	248.51	24.54
	100g Wheat Starch	75.90	27.66



Second harvest of 100g sugar sample



Second harvest of 100g wheat starch (unfiltered glucose) sample



Second harvest of 75g wheat starch (reduced resources) sample



Second harvest of 75g wheat starch (reduced resources) sample

Pellicle Purification

Purification enhances the mechanical properties of kombucha bacterial cellulose, especially with sodium hydroxide, but the main goal is to reduce the brown coloration caused by black tea. This study tested whether sodium hydroxide could produce a whiter pellicle. The method, compiled from various sources, involved:

1. Soaking the wet pellicle in ethanol.
2. Boiling in distilled water for 40 minutes.
3. Two 20-minute soaks in hot sodium hydroxide.
4. Thorough washing with distilled water.
5. Soaking in diluted acetic acid for 5+ hours.

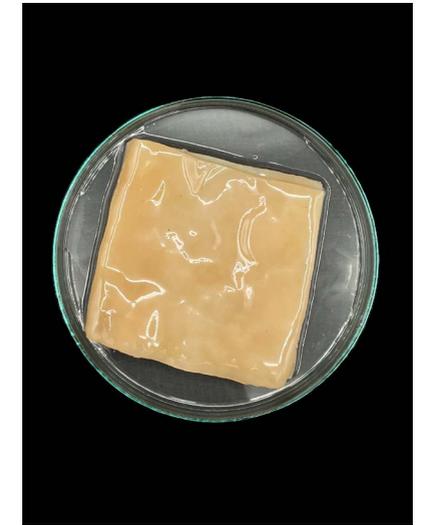
Results

Two samples were tested: one with black tea (conventional recipe) and one without (reduced resources). Minimal color differences were observed, with a slight lightening but a dulled appearance and loss of shine post-purification.

Given the time-consuming process, high water usage, and reliance on sodium hydroxide, further purification was deemed unnecessary. Subsequent tensile strength tests and pellicle processing revealed that purified pellicles exhibited decreased tensile strength, becoming drier and more fragile. Instead, pellicles were washed post-harvest with dish soap to remove excess bacteria and residue, then gently patted dry for use in further stages.



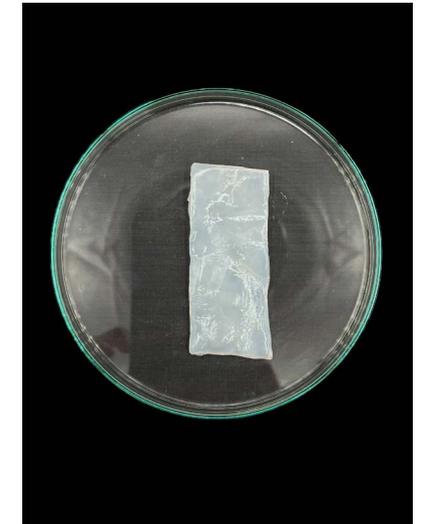
Unpurified sample (100 wheat starch, unfiltered glucose)



Purified sample (100 wheat starch, unfiltered glucose)



Unpurified sample (50g wheat starch, reduced resources)



Purified sample (50g wheat starch, reduced resources)

Tensile Strength Test

Standard: ISO 527-1 (2019)
Head Speed: 10mm/N
Minimum Load: 5N
Probe Dimensions: 60mm by 15mm

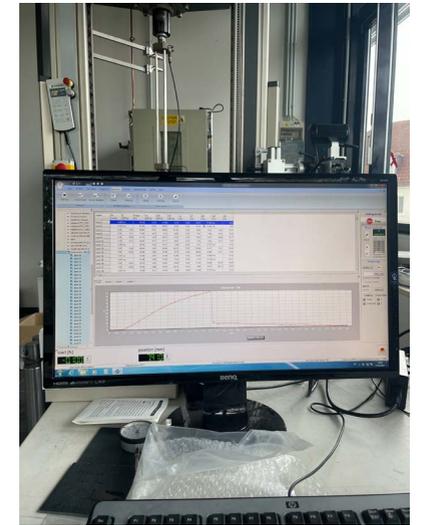
The objective of the tensile strength test was to determine the material strength of each sample and to enable a comparison among them, aiming to identify the sample that exhibits the highest tensile strength for potential scalability in the final product application.

For the test setup, all pellicle samples were first air-dried before being cut into probes measuring 60mm by 15mm. This follows the dimensions outlined in Nadia Elkady's master's thesis, *Microbial Leather*. The thickness of each probe was measured using a thickness gauge. Due to the lack of standardized testing procedures, errors occurred during the initial execution of the tensile strength testing. Consequently, the results from this testing phase were intended solely for comparison within the scope of this research to identify the sample with the highest tensile strength.

During testing, a key issue was the insufficient number of probes per sample. A minimum of three probes is required for reliable results, but limited pellicle availability led to inconsistent testing. One pellicle developed mold while air-drying, likely due to being covered with cling film to protect other students' materials. The shortage of pellicles reduced the number of probes for testing, and time constraints prevented replicating samples. Additionally, the thin probes made it difficult to secure the material in the clamps, causing slippage and slower stretching during tests.



Thickness of probes measured



Results recorded



Tensile strength test in process

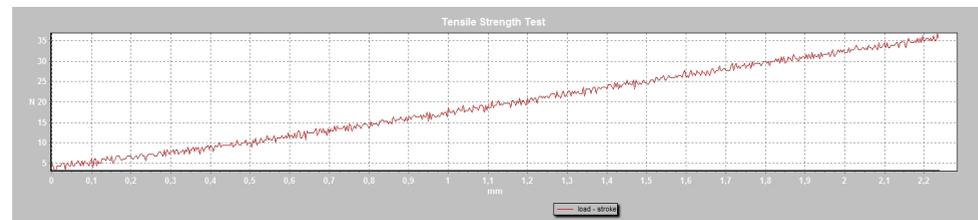


Before and after tensile strength test on sample 125g wheat starch (filtered glucose)

	Sample	Unpurified Pellicle			Purified Pellicle		
		Test #	Thickness (mm)	Fmax (N)	Test #	Thickness (mm)	Fmax (N)
Phase #1	100g Sugar	10	0.30	14.60	22	0.13	10.00
		9	0.07	17.70	23	0.08	12.10
		11	0.04	18.20	24	0.04	8.00
		13	0.04	14.40			
	100g Wheat Starch	12	0.30	60.60	25	0.20	10.90
		14	0.14	25.90	26	0.09	11.60
		15	0.10	21.40	27	0.08	13.00
		16	0.11	22.70	28	0.05	15.20
	250g Wheat Starch	17	0.25	52.20	29	0.23	12.20
		18	0.08	12.90	30	0.12	16.10
		19	0.06	12.20	31	0.11	29.40
		20	0.07	5.00	32	0.10	19.40
21		0.07	12.00				
Phase #2	75g Wheat Starch	33	0.14	29.80	39	0.09	17.10
		34	0.08	33.80	40	0.12	16.00
		35	0.08	38.20	41	0.07	9.10
		36	0.07	21.40	42	[error]	[error]
		37	0.07	29.90	43	[error]	[error]
	38	0.07	21.10	44	0.14	5.10	
	100g Wheat Starch	54	0.31	92.60			
		55, 56, 58	0.24	103.60			
		59-62	0.28	85.23			
		63-66	0.31	85.98			
	125g Wheat Starch	72, 73	0.28	90.80			
		74	0.29	106.00			
75		0.21	104.20				
76		0.27	95.20				
Phase #3	50g Wheat Starch	52	0.14	38.70	45	0.21	14.50
					46	0.06	12.10
					47	0.08	8.40
	75g Wheat Starch	53	0.08	36.70	48	0.09	10.70
		94	0.14	41.00	49	0.08	11.30
		95	0.16	50.50	50	0.13	21.20
		96	0.14	46.00	51	0.10	14.70
	100g Wheat Starch	88	0.15	13.90			
		89	0.16	14.40			
		90	0.09	14.00			
		91	0.10	12.30			

Left. Table of results: overview tensile strength values (top) and tensile strength average values (bottom).

	Sample	Unpurified Pellicle		Purified Pellicle	
		Thickness (mm)	Fmax (N)	Thickness (mm)	Fmax (N)
Phase #1	100g Sugar	0.05	16.77	0.08	10.03
	100g Wheat Starch	0.12	23.33	0.07	13.27
	250g Wheat Starch	0.07	10.53	0.11	21.63
Phase #2	75g Wheat Starch	0.09	29.03		
	100g Wheat Starch	0.29	91.85		
	125g Wheat Starch	0.26	99.05		
Phase #3	50g Wheat Starch	0.14	38.70	0.07	10.25
	75g Wheat Starch	0.13	43.55	0.01	14.48
	100g Wheat Starch	0.13	13.65		



Tensile strength graph of test #53 (75g wheat starch utilizing filtered glucose and reduced resources)

Results

The results were categorized based on the sample types and wheat starch content. Each probe was assigned a test number, its measured thickness (mm), and its maximum force (N) for both unpurified and purified pellicles. Any anomalies, highlighted in red on the overview table of tensile strength values, were not factored into the following table displaying average scores. For instance, in the sample test of 100g sugar, test #10 displayed a significantly larger thickness of 0.30 compared to the other three probes. The second table showcases the calculated average scores for each sample. Anomalies highlighted in red were disregarded when comparing samples, while highlighted in green indicated promising results for further consideration.

Unfiltered vs. Filtered Glucose

A comparison between filtered and unfiltered glucose was made using unpurified 100g wheat starch (test #12 vs. #54). The filtered sample showed approximately 1.5 times higher tensile strength than the unfiltered sample.

Unpurified vs. Purified Pellicle

Purified samples consistently exhibited lower tensile strength than unpurified ones. The purified material felt drier and was more prone to breakage under minimal force.

Reduced Resources

When analyzing the influence of black tea, SCOBY and vinegar on tensile strength, comparisons of 75g wheat starch utilizing filtered glucose and reduced resources showed a higher tensile strength. Tests with the same thickness (e.g., test #33, #94, #96 at 0.14 mm; test #34, #35, and #53 at 0.08 mm) confirmed this.

Large Scale Production

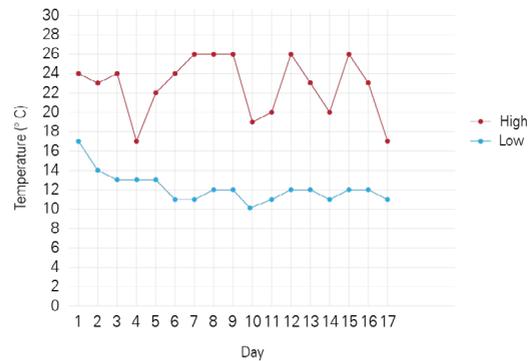
With the 75g wheat starch sample utilizing filtered glucose and reduced resources yielding the most promising results, its recipe was chosen to be replicated on a larger scale in the next stage.

Confounding Variable: Temperature

Throughout the growth phase of the thesis, temperature emerged as a confounding factor, impacting the studied variables and making it challenging to discern their causal relationship. To address this, daily high and low temperatures were recorded during each fermentation process, spanning from the initial brew preparation to the day of pellicle harvest. A consistent weather forecasting website was used for temperature data consistency.

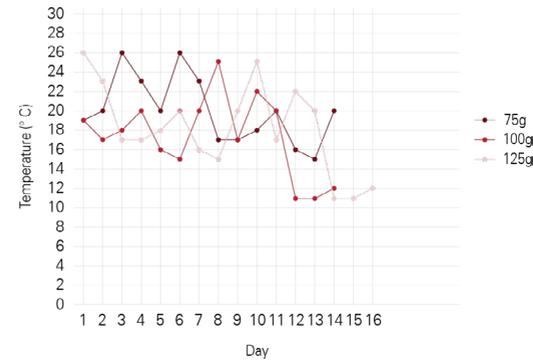
Diagrams presented below were generated based on this data to facilitate data analysis, allowing for a comparative analysis of results. This aimed to account for potential variables and to identify trends or patterns in the data.

Sucrose vs. Glucose
High Temperature



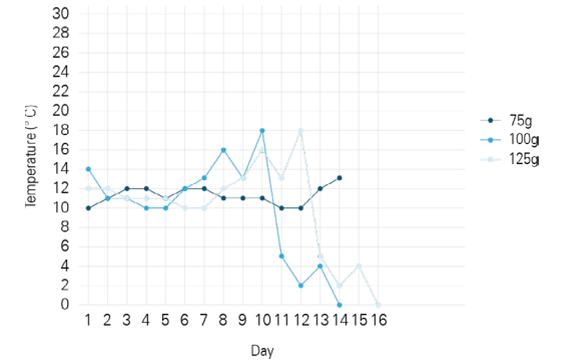
Graph showing temperature variation during fermentation process of 100g sugar, 100g, and 250g wheat starch samples using unfiltered glucose

Filtered Glucose (75g, 100g, 125g wheat starch)
High Temperature



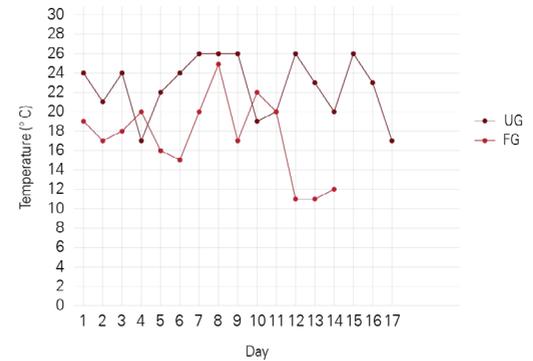
Graph showing high temperature variation during fermentation process of 75g, 100g, and 125g wheat starch samples using filtered glucose

Low Temperature



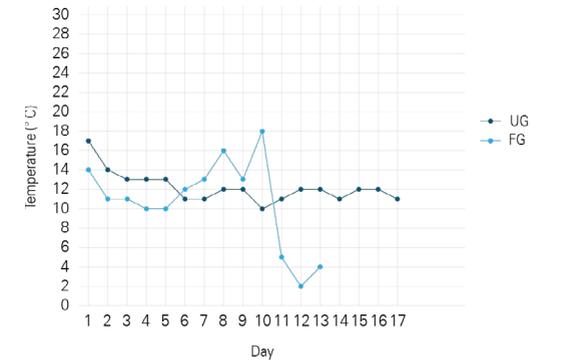
Graph showing low temperature variation during fermentation process of 75g, 100g, and 125g wheat starch samples using filtered glucose

Unfiltered Glucose vs. Filtered Glucose (100g wheat starch)
High Temperature



Graph showing high temperature variation during fermentation process of 100g wheat starch samples using unfiltered and filtered glucose

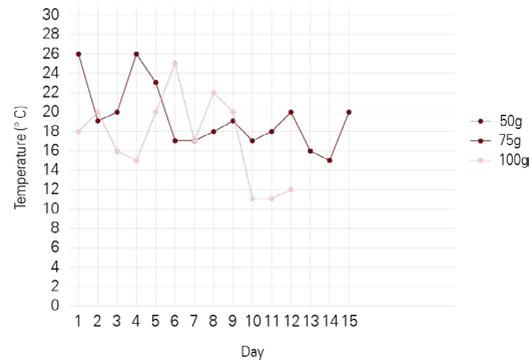
Low Temperature



Graph showing low temperature variation during fermentation process of 100g wheat starch samples using unfiltered and filtered glucose

Reduced Resources (50g, 75g, 100g wheat starch)

High Temperature



Graph showing high temperature variation during fermentation process of 50g, 75g, and 100g wheat starch (reduced resources) samples using filtered glucose

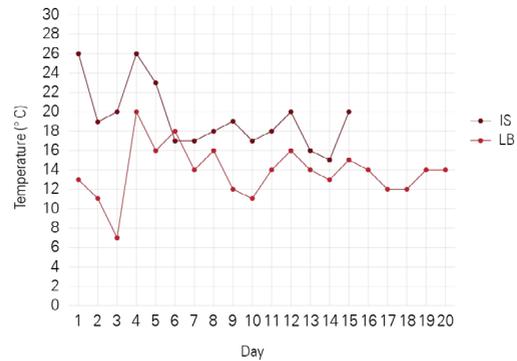
Low Temperature



Graph showing low temperature variation during fermentation process of 50g, 75g, and 100g wheat starch (reduced resources) samples using filtered glucose

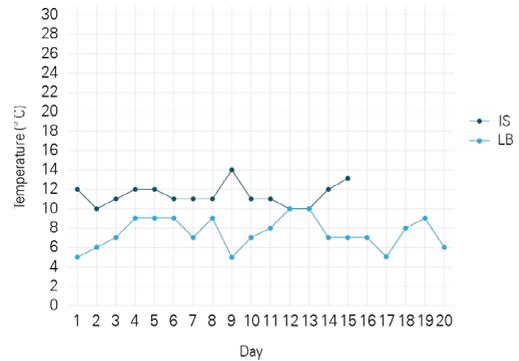
Initial Sample vs. Large Batch (75g wheat starch)

High Temperature



Graph showing high temperature variation during fermentation process for initial and large batch samples of 75g wheat starch (reduced resources) utilizing filtered glucose

Low Temperature



Graph showing high temperature variation during fermentation process for initial and large batch samples of 75g wheat starch (reduced resources) using filtered glucose

Conclusion

The findings suggest that, contrary to earlier assumptions, unfiltered glucose does not negatively impact the growth rate and quality of kombucha pellicles. Filtered glucose samples exhibited thinner and slower growth compared to those grown in unfiltered glucose. Temperature analysis indicates that the enhanced growth rate observed in the unfiltered glucose samples may be attributed to more stable and warmer conditions that support the development of kombucha bacterial cellulose. Furthermore, tensile strength tests revealed that samples utilizing 75g of wheat starch with filtered glucose achieved the highest scores, highlighting temperature as a crucial factor in cultivating kombucha materials.

Hand-spinning into Threads

Extruding blended pulp: The method involved blending the pellicle into a fine pulp, subsequently extruded into thread-like strands and left to dry.

A few obstacles were encountered during this process. Initially, blending the pellicle into a fine pulp posed a challenge due to its resilient, gel-like nature. Attempts with an electric blender were unsuccessful due to the small amount of pellicle, therefore resorting to manual cutting with a sharp knife until a paste-like consistency was achieved. The following hurdle involved extruding the paste into long strands using a syringe, requiring meticulous handling assisted by a knife for strand creation for air-drying.

The resulting strands were fragile and susceptible to breakage when subjected to slight force due to the loosened structure and binding of the blended pulp. This fragility was seemingly attributed to the pellicle's water retention, which, when dissipated, resulted in gaps within the damaged structure. Given the labor-intensive and time-consuming nature of this method, it appeared unsuitable for a material that exhibited considerable fragility.



Blending of pellicle into fine pulp, extruded into strands



Hand-cutting pellicle until a paste-like consistency was achieved



Pellicle pulp arranged into long strands for air drying



Unsuccessful syringe extrusion of pulp



Dried strands of pulp

Extruding using a sharp, hollow needle: The method involved attempting to cut a strand of pellicle by extruding a sharp, hollow needle into it. For testing purposes, a SCOBY that was no longer needed was used. However, the attempt was unsuccessful in cutting through the strong, jelly-like structure of the pellicle, as the needle simply poked a hole through it.



Unsuccessful attempt to extrude a strand of pellicle using a sharp, hollow needle

Dissolving ground pellicle: The method was derived from a scientific research study utilizing Glycerin/NaOH Aqueous Solution as an eco-friendly solvent system for cellulose dissolution. Adjustments were made to accommodate available resources.

The modified method involved the following steps:

1. Adding one gram of glycerin and 9.0 grams of NaOH into 90 mL of deionized water to create the mixed aqueous solution of glycerin/NaOH.
2. Incorporating the ground pellicle into the mixture and allowing it to swell for 6 hours at room temperature. Precooling the suspension to -20 °C and maintaining it at that temperature overnight to solidify. Vigorously stirring the frozen solid until complete thawing
3. to obtain cellulose solutions.

However, progress halted at the second step as the mixture showed no observable swelling, remaining unchanged after several days. Consequently, this method was unsuccessful.



Drying pellicle



Dried pellicle blended into powder



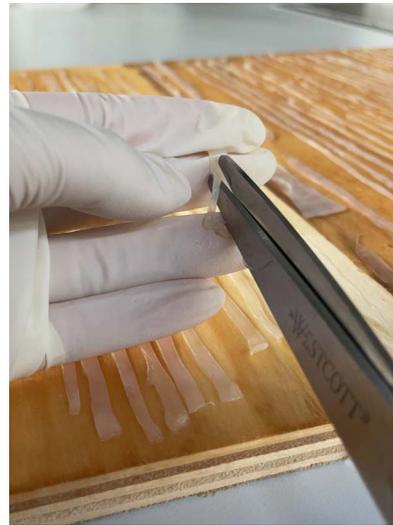
Blending pieces of dried pellicle



Unsuccessful attempt to dissolve dried pellicle powder

Cutting and handspinning: This approach included cutting the pellicle into thin strands, aiming for an evenness similar to thread size, and allowing it to air-dry before hand-spinning it into a thread. The process revealed that spinning the material while retaining some moisture ensured a more seamless and robust binding during the twisting process.

Despite being time- and labor-intensive, this method emerged as the only effective one among the four tested. Hence, this technique was used for transforming pellicles into threads in the subsequent production.



Pellicle cut into thin, long strips



Cut strips ready for air-drying



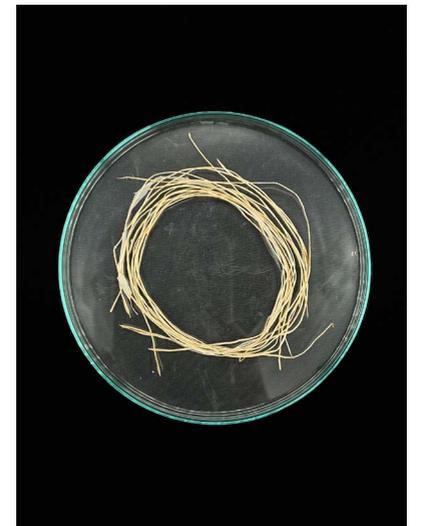
Handspinning attempt to transform cut strip into a thread



Handspun sample



Attempts to transform cut strip into a thread



Handspun sample

Method Refined



Pellicles grown over 3-4 weeks



Process of cutting pellicles by hand



Pellicle harvested and washed with dish soap



Pellicles cut into long strands



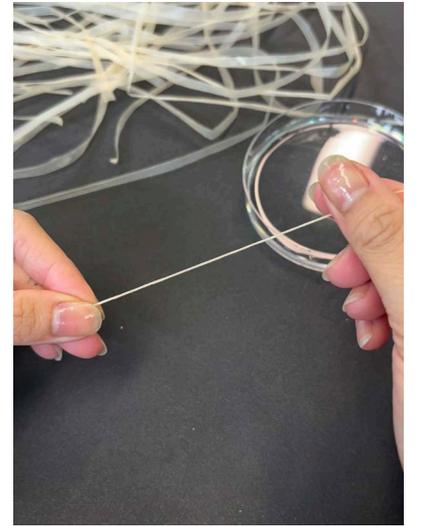
Pellicles cut in strands, ready for air-drying



Process of handspinning



Partially dried pellicle strands



Handspun kombucha thread



Process of handspinning

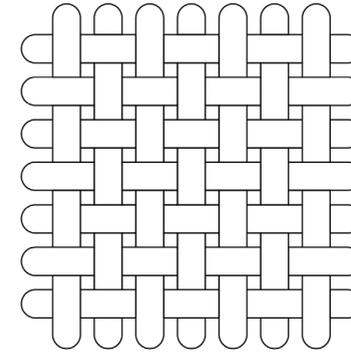


Handspun kombucha threads

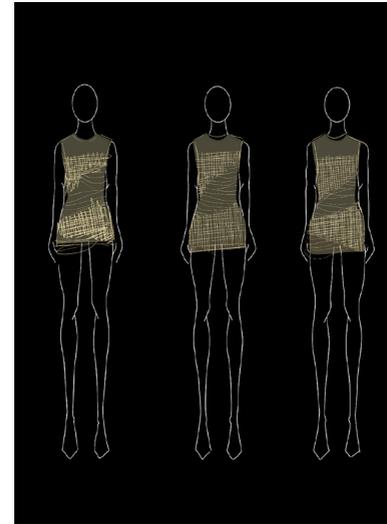
Material Applications

In exploring material applications, the primary goal was to gain a comprehensive understanding of kombucha threads and to effectively demonstrate their potential by incorporating them into a woven garment. This process began with the decision to utilize a plain weave, which is the most commonly used weaving technique in garment construction.

This technique aimed to observe how kombucha threads perform not only in isolated sections but as part of a cohesive whole, allowing for a thorough assessment of their structural integrity and functional properties. The choice of plain weave offered a straightforward method to facilitate a clear examination of how the kombucha threads behave under various conditions, such as tension and durability.



Technical drawing of a plain weave



Design sketches

Woven Kombucha Dress

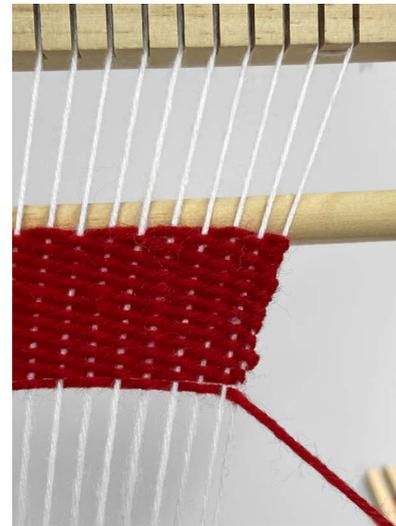
The garment concept was designed to align closely with the core focus of the thesis, which emphasizes the biodegradability of regenerative materials within the context of a circular fashion economy. To achieve this, the weaving technique was employed to visually convey the process of biodegradation, illustrating how the garment transforms as it is worn, thus fostering a dialogue about the lifecycle of materials.

Throughout the prototyping phase, various methods were explored to bring this vision to life. This iterative process allowed for a deeper understanding of how to effectively communicate the themes of regeneration and circularity through the medium of fashion.

Miniature Prototype

The initial step involved using the yarn that came with the loom to familiarize with the weaving technique. Employing the plain weaving technique, adjustments were made to reduce the spacing between threads on the loom designed for thicker materials, as it resulted in an overly loose weave. Subsequently, a different material, 100% cotton threads similar in appearance, was used for prototyping the weaving process. The goal was to convey the appearance of garment biodegradation on the wearer.

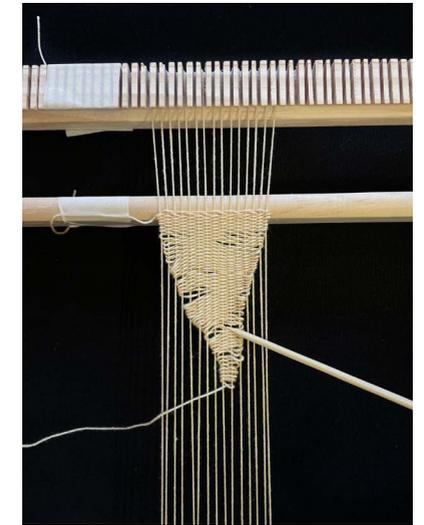
The first attempt involved weaving followed by cutting parts of it, but this did not yield the desired effect. The second attempt was adjusted by varying the tightness of the weave. It ranged from tightly woven on the left side and gradually became loosely woven as it moved towards the right side of the top. Additionally, some threads were left loosely hanging and fewer areas were woven. Slight modifications were made to enhance cohesiveness between the top and skirt to create a more connected yet disassociated appearance, tying in the concept of biodegradation—the gradual disintegration of a garment.



First prototype of plain weave using yarn and a handloom



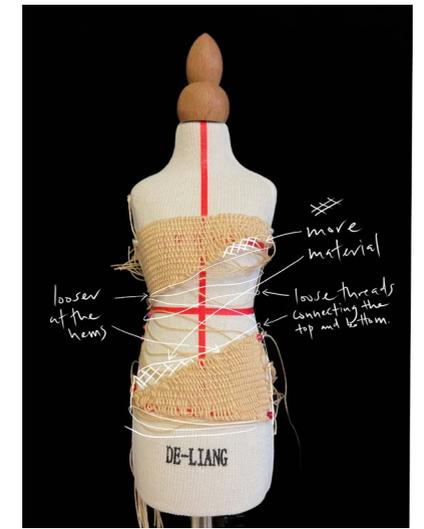
Wide gaps on handloom created a loose weave structure



Miniature prototype of the skirt using prototype threads (100% cotton)



Prototype using kombucha threads



Miniature prototype of the final dress using prototype threads

Weaving Process

Creating a top prototype using kombucha threads proved time-consuming due to the material's natural properties. During the weaving process, it was observed that the plain weave created a tight, high-tension, and compact structure, which may have been unsuitable for using solely kombucha threads.

Additionally, kombucha bacterial cellulose is strongest in its wet state, most clearly seen upon harvest. Increased fragility and proneness to breakage were apparent the drier the material became. Therefore, they had to be handled very carefully, and ensured consistent reapplication of water throughout the entire process of weaving, cutting, and putting together of the final garment. Fortunately, with water, the kombucha threads can be instantly rehydrated and transformed into its original gelatinous form.

Rehydration was first tested using the steam from an iron for minimal and controlled application of water, but resorted to a more efficient method of simply running small amounts of water across the threads by hand. The rehydration of threads ensured greater flexibility, lower likelihood of breakage, and increased workability of the material.

Moreover, the lack of flexibility in the threads led to frequent snapping as they dried. To address this, a weaver's knot was used each time a thread broke to join the two ends. However, this caused difficulties, as the knots interrupted the seamless weaving process and affected the visual appeal, despite efforts to tuck the ends underneath for a smoother finish.



Handspun kombucha thread, susceptible to breakage due to the lack of uniformity during cutting stage



Breakage of thread during weaving process



Weaver's knot to connect two ends of kombucha thread

Refinements

Given that the decision to incorporate colored threads was made after the fermentation process had begun, the pellicles were dyed upon harvest as opposed to adding the hibiscus into the brew to allow the pellicles to grow into the color during the fermentation process. The dye was prepared by soaking the dried hibiscus in boiled water for approximately two-three hours. The pellicles were then placed into the dye for overnight to ensure complete absorption of color.



First sample of the dress



Kombucha film initially served as a base but later removed due to persisting wrinkles



Dried hibiscus



Handspinning dyed threads



Pellicles soaked in hibiscus dye



Process of handspinning a dyed thread



Understanding the Properties of Kombucha Threads

This section summarizes the insights gained from the research on kombucha threads, which formed the basis for further exploration during the residency supervised by Prof. Dr. Manuel Kretzer and Virginia Binsch. This residency provided a unique opportunity to extend the material research and development into practical textile applications, conducted at the Materiability Research Group's Biolab at Anhalt University.

The focus of this residency was to experiment with kombucha threads in garment structures, addressing challenges related to their commercial viability due to environmental instability. To tackle these limitations, weaving techniques were prioritized over knitting and crocheting, based on insights gained from previous research and consultations with field experts. By co-weaving kombucha threads with other biodegradable materials, this project aimed to enhance durability and strength while deepening the understanding of kombucha threads as a functional textile. Experimenting with various material combinations and weaving techniques represents a significant advancement in exploring the potential of this bio-based material.

Kombucha threads exhibit flexibility and softness that fluctuate with environmental conditions—a fascinating yet reversible characteristic that currently limits their stability for textile applications. The development of kombucha threads for weaving is still in its early stages and requires further study. However, as an evolving material, kombucha threads show promising potential. They can be woven with other natural yarns to create dual or tri-blend fabrics, allowing for tailored textures that range from soft and moldable to firm and shape-retaining.



Kombucha bacterial cellulose threads



Breakage of kombucha thread during the weaving process caused by uneven cutting and insufficient moisture content

Insights from working with kombucha threads highlight their structural reinforcement potential, particularly useful in applications like corsetry, where they can replace traditional, non-biodegradable materials such as polyester. Kombucha threads offer precise reinforcement without the need for insertion, integrating seamlessly into the garment while remaining fully biodegradable.

Conventional corsets made with plastic or steel boning often cause discomfort, particularly when seated, as the boning can dig into the skin and pierce through the fabric, damaging the garment. By replacing synthetic boning with natural, biodegradable kombucha boning, these issues are mitigated while maintaining the intended functionality and support of the corset. This approach ensures the garment holds its shape and allows for unrestricted movement, balancing comfort and structural integrity. The combination of kombucha threads with an alternative softer yarn strikes a perfect balance for creating comfortable, wearable garments.

In this phase of material application, the aim was to construct a corset from kombucha threads co-woven with other natural materials. Ensuring the complete biodegradation of the product at the end of its lifecycle remained a critical focal point in the study.

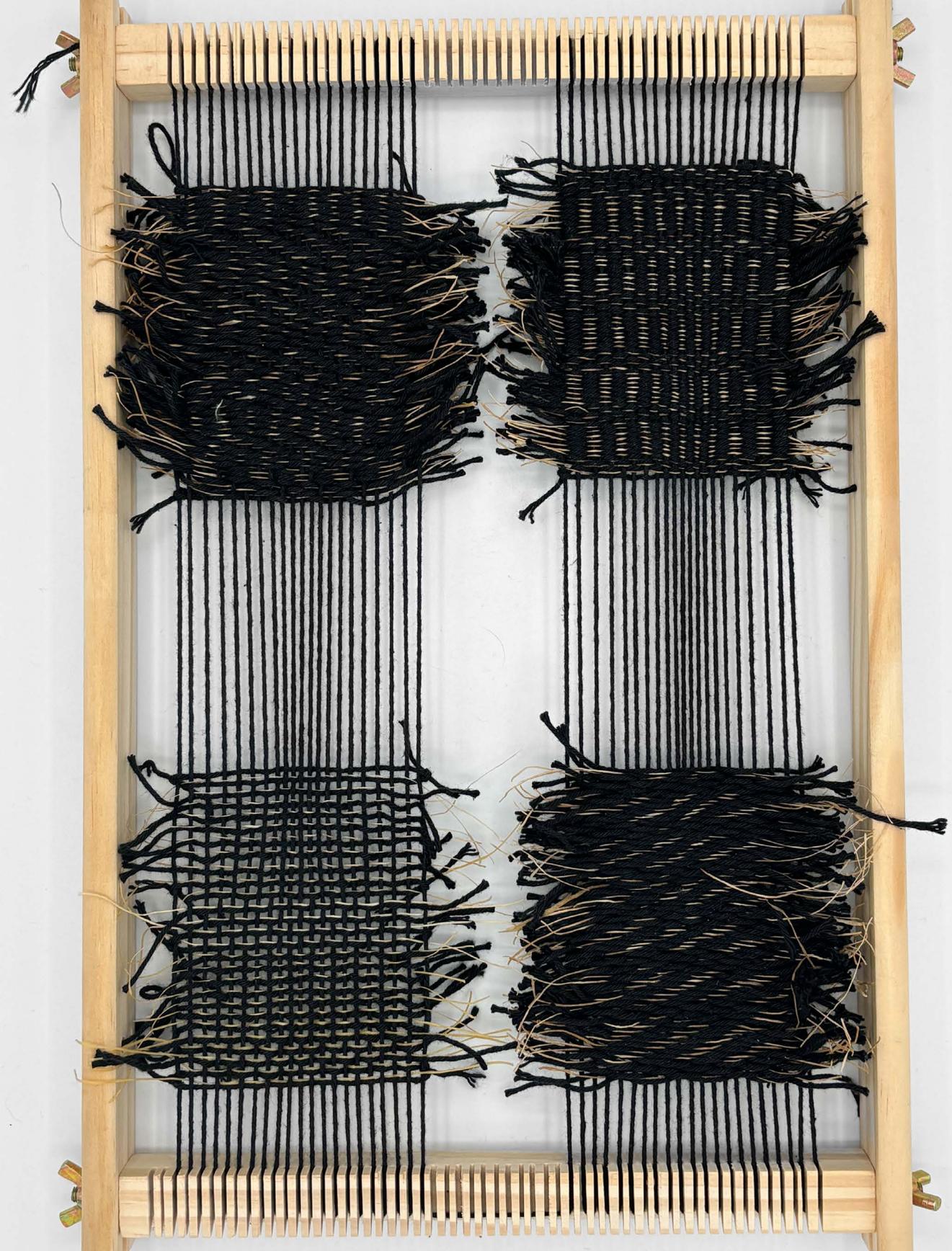
Woven Hybrid Corset

To achieve this, an experimental study was conducted to test the collective influence of different materials combinations as well as weaving techniques on the textural behavior of the resulting fabric. The interplay between material combinations and weaving techniques offered extensive adaptability.

Depending on the intended function and aesthetic of the garment, the interplay allowed for adjustments in thickness, softness, and structure.

Experimenting with different material combinations offers extensive possibilities for a fabric's texture, impacting its physical appearance, handfeel, and suitability for various occasions. Physical appearance factors include thickness, thinness, structure, and conformity, while handfeel considerations involve flatness, three-dimensionality, softness, stiffness, and flexibility. Occasion suitability ranges from casual to evening and business casual. In the study, thicker yarns were anticipated to create a more three-dimensional or "puffy" exterior, lending themselves to a casual look, while thinner yarns or threads were expected to produce a flatter exterior, suitable for formal, evening wear due to their finer needlework.

Additionally, experimenting with weaving techniques can yield a variety of textures, influencing both physical appearance and handfeel. The study focused on three fundamental weaving techniques: plain weave, twill weave, and satin weave. Plain weave was predicted to produce the tightest fabric with the most tension, while satin weave was expected to result in the softest fabric with the least tension. Twill weave, commonly used for jeans, was anticipated to create the stretchiest fabric.



Experimentation

To facilitate clearer observations during experimentation, certain variables were kept constant, including the weaving sequence and the colors of the alternative materials and kombucha threads. The alternative materials were kept black, while the kombucha threads retained their natural yellow color, maintaining a black and yellow color palette. Two control samples were woven for later comparison: one with kombucha threads and another with merino wool/silk yarn, both in plain weave.

The experimental approach was systematic, changing one variable at a time while keeping everything else constant to observe each effect. The alternative materials tested included 80% merino wool/20% silk yarn, 100% cotton yarn, and 100% Lyocell thread. For each material, a sample was woven in plain weave, twill weave, and satin weave. Since Lyocell threads are fine, they were looped in sets of seven and then woven. All samples were kept in A7 size, allowing for more extensive sample testing.

CONTROL SAMPLES

00-1
KOMBUCHA
PLAIN WEAVE

00-2
MERINO WOOL/SILK
PLAIN WEAVE

MATERIAL COMBINATIONS WEAVING TECHNIQUES

01
MERINO WOOL/SILK X KOMBUCHA
PLAIN WEAVE
Twill WEAVE
SATIN WEAVE

02
COTTON X KOMBUCHA
PLAIN WEAVE
Twill WEAVE
SATIN WEAVE

03
LYOCELL X KOMBUCHA
PLAIN WEAVE
Twill WEAVE
SATIN WEAVE



Kombucha threads in plain weave



Merino wool/silk yarn in plain weave



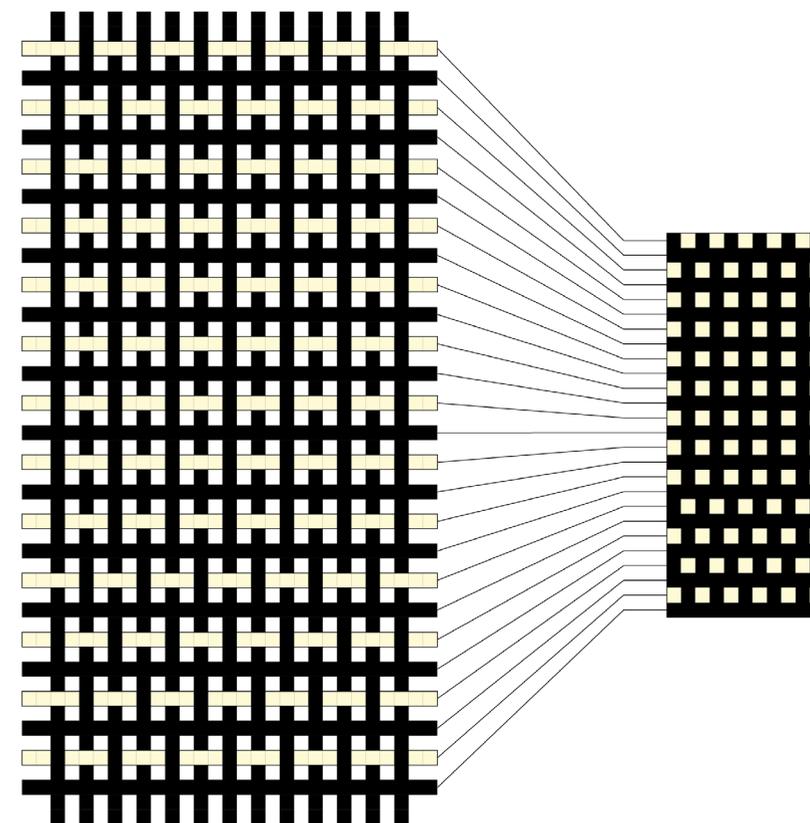
100% cotton yarn



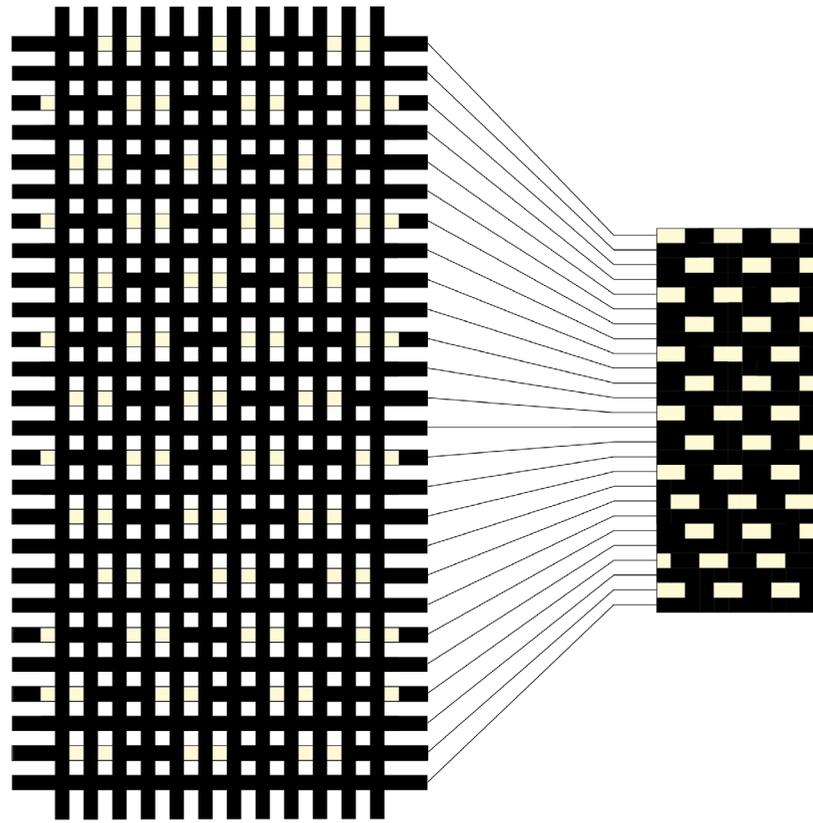
80% merino wool/20% silk yarn.



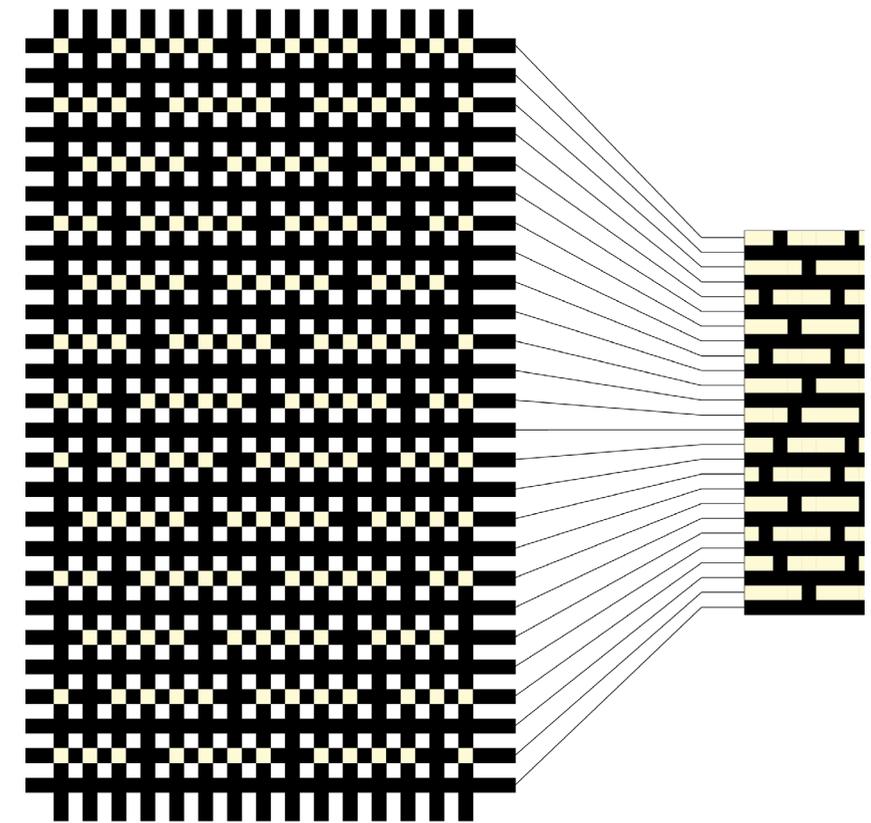
100% Lyocell threads



Technical drawing of the plain weave and sequence used in the study



Technical drawing of the twill weave and sequence used in the study



Technical drawing of the satin weave and sequence used in the study

Woven Samples

The weaving experiments, focusing on the collective influence of different weaving techniques and material combinations, yielded several significant insights. Fabrics woven solely from kombucha threads resulted in a very tough material, which may not be comfortable to wear. In contrast, samples woven from merino wool/silk yarn produced extremely soft and flexible fabrics, perfect for draping. When combined, as demonstrated in the merino wool/silk and kombucha samples, a balance between softness and stiffness was achieved. This balance can be adjusted to become softer or stiffer depending on the ratio and sequence of the two types of materials used.

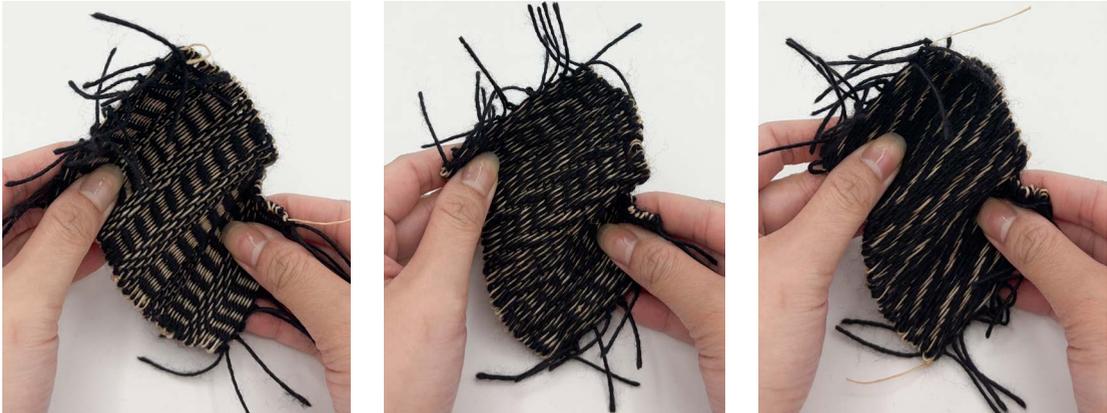
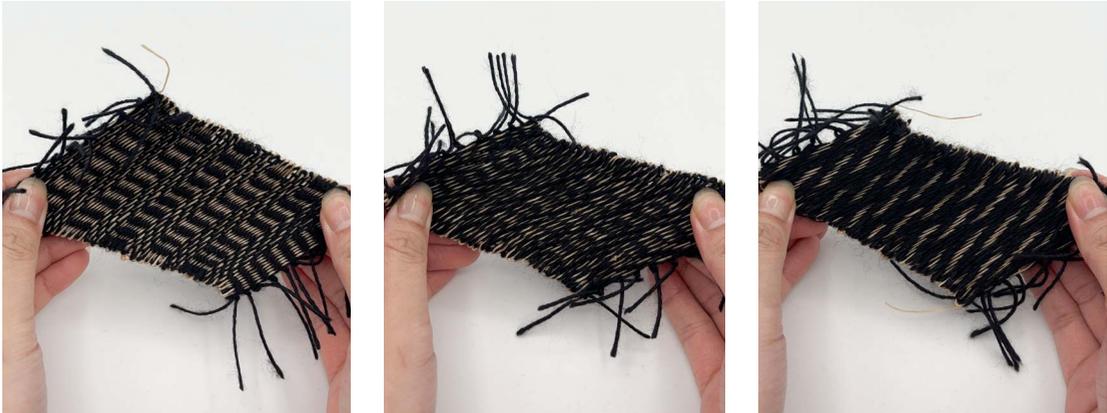
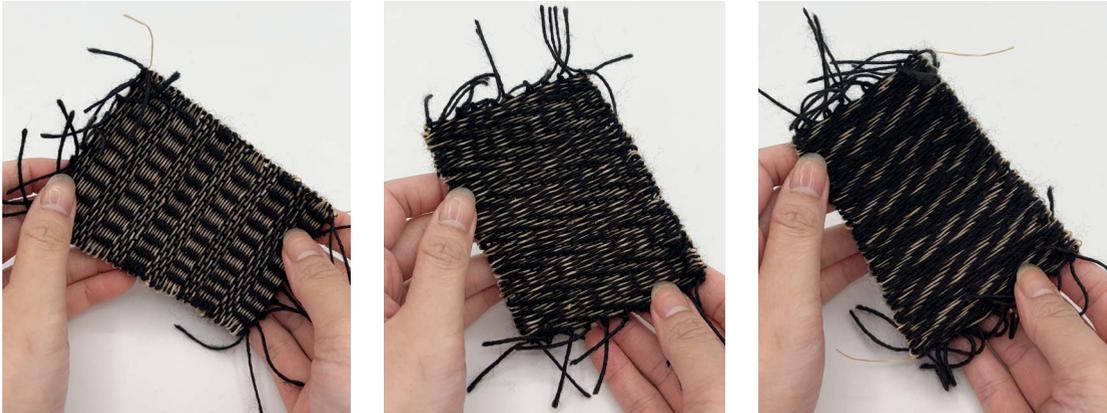
All samples were woven on a handloom. It was found that weaving kombucha threads horizontally maximizes freedom of movement, especially when sitting due to the positioning of kombucha threads. The stiffness of dried kombucha threads helped the fabric hold its shape, effectively wrapping the torso of the wearer tightly.

The visual emphasis of material proportions was also evident throughout the samples. In the Lyocell-kombucha samples, the higher ratio of kombucha to Lyocell made the kombucha threads more prominent, while in the cotton-kombucha samples, the emphasis was on the cotton yarn. This indicates that material selection can be tailored to achieve the desired design outcome.



Merino Wool/Silk Yarn

80% merino wool/20% silk yarn produced a smooth, silky fabric with a luxurious feel and sheen. This material is generally flatter and lacks volume, making it more suitable for thinner garments like T-shirts, while still offering some elasticity and a slight fuzz from the wool content.



Plain weave

Twill weave

Satin weave

Plain weave

Twill weave

Satin weave

Cotton Yarn

The 100% cotton yarn resulted in a coarser yet still soft fabric, giving a more casual feel across all weaving techniques. This thicker yarn produced greater volume, creating in a chunkier look reminiscent of a casual knitted sweater in a woven form.



Plain weave



Twill weave



Satin weave



Plain weave



Twill weave



Satin weave

Lyocell Threads

The 100% Lyocell threads created an even thinner fabric than the merino wool/silk yarn, with a very silky touch. However, this fabric was generally stiffer across all weaving techniques due to the lack of volume and inherent softness, resulting in a clean, refined appearance.



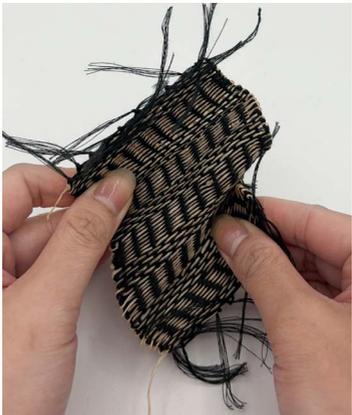
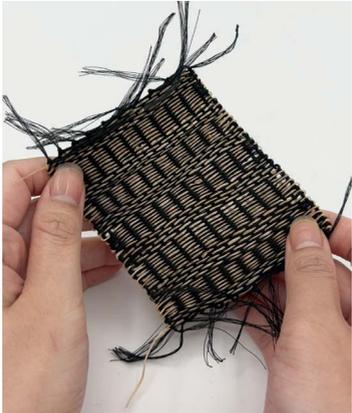
Plain weave



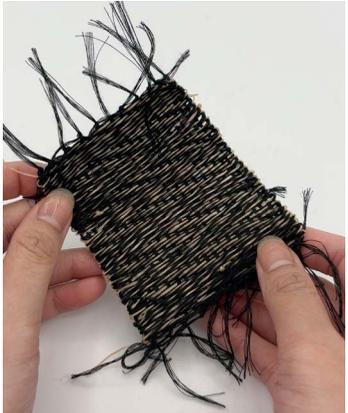
Twill weave



Satin weave



Plain weave



Twill weave



Satin weave



Double knot to hold the woven sample in place

Weaving Techniques

In terms of weaving techniques, satin weave produced the softest fabric with the most volume. Twill weave resulted in the most stretchy fabric, as demonstrated in the accompanying photos. Plain weave created the stiffest and tightest fabric, with the most tension during weaving, leaving little to no space between threads—this was especially noticeable in the kombucha thread sample, which tightened and narrowed significantly.

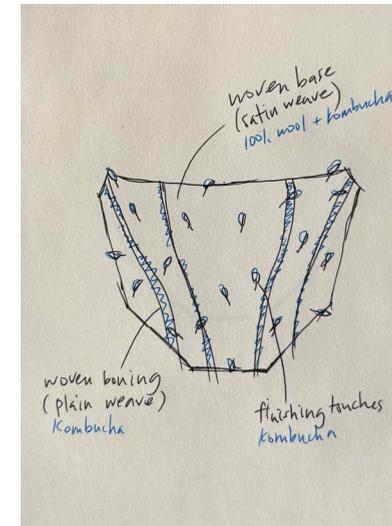
Based on the findings, moving forward to the design phase, a new material—100% wool—was introduced to extend beyond the tested materials. This addition aimed to provide increased volume and softness, achieving a more luxurious look suitable for evening wear. Combining this wool with kombucha threads woven in a satin weave enhanced the fabric's puffiness, volume, and softness.

Ideation

The concept of using kombucha threads in corset design stems from their ability to provide subtle structure similar to traditional corset boning, which typically involves inserting plastic or steel to shape and support the garment. Kombucha threads offer a natural, circular material alternative that integrates seamlessly into the woven fabric of the corset, delivering the necessary functionality in a more refined way.

Combining kombucha threads with 100% wool was chosen based on woven sample learnings, which highlighted enhanced three-dimensionality, softness, a luxurious feel, and a contrast between the thick wool yarn and fine kombucha threads. This hybrid material combination leverages the softness and stable flexibility of wool with the stiffness of kombucha threads, providing precise reinforcement of structure and shape to targeted areas—an essential quality for shaping the body in a corset.

Satin weave was selected for its softness and comfort, addressing the common discomfort and stiffness associated with traditional corsets, making them easier and more pleasant to wear. Finishing touches include petal-like detailing crafted from kombucha threads, showcasing the material's versatility and design potential for garments, and highlighting its reversible nature.



Sketch of corset design



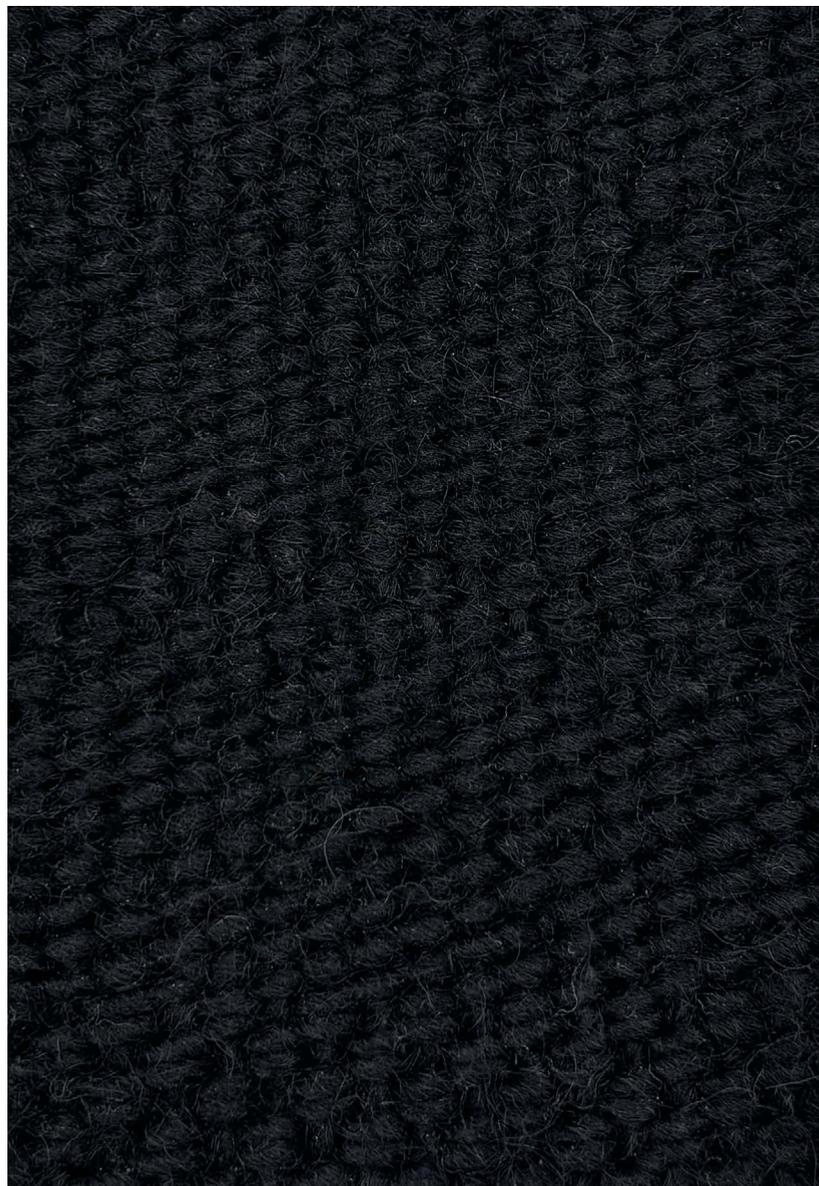
Corset boning with kombucha threads



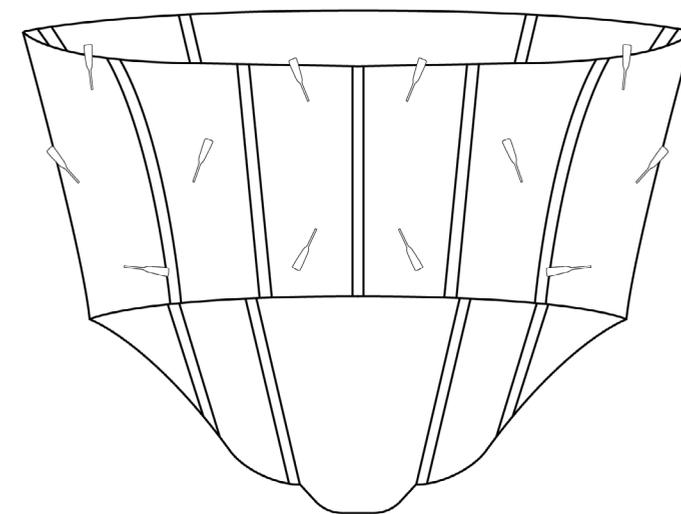
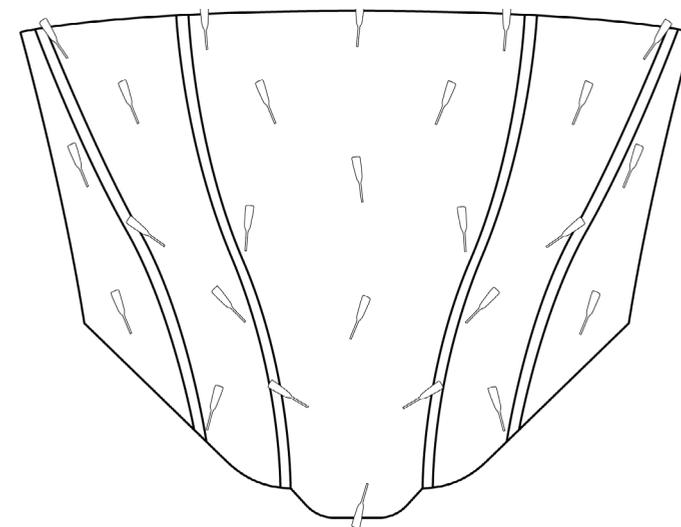
Kombucha bacterial cellulose threads



100% wool yarn



100% wool yarn in plain weave



Technical drawing of corset design



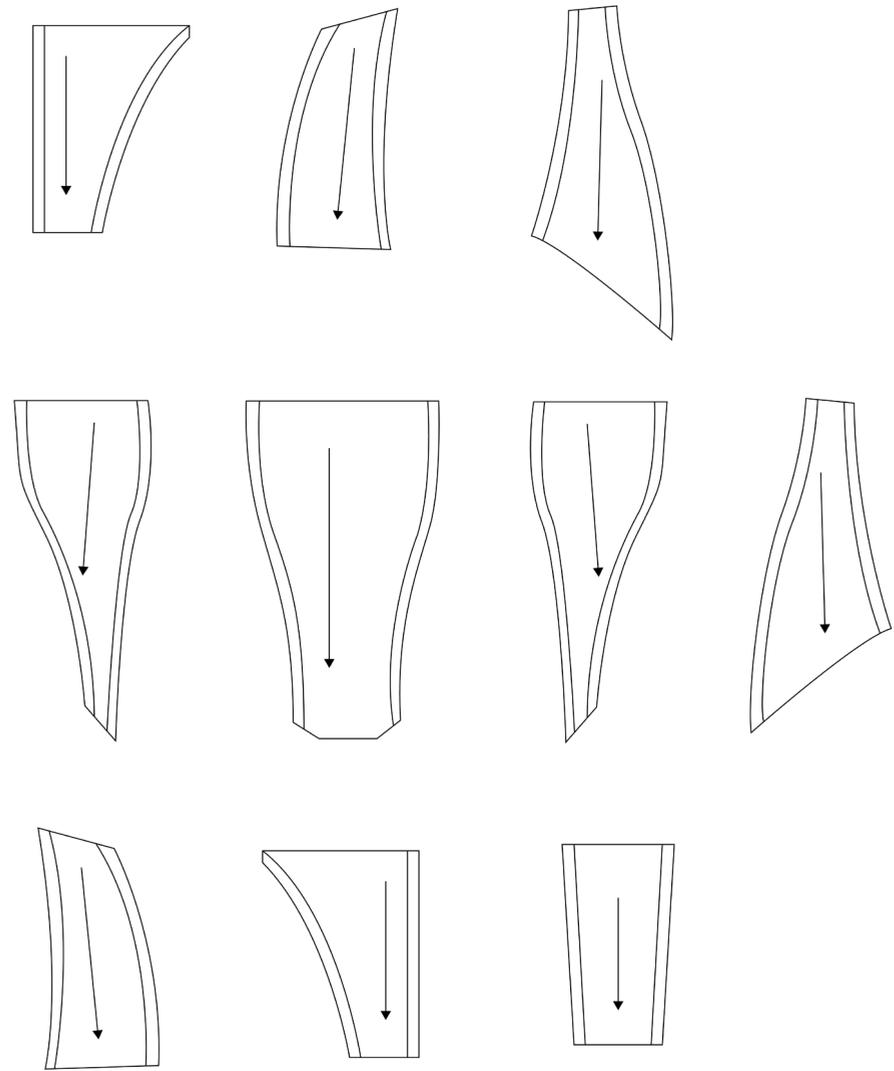
Translucent quality of kombucha material when exposed to sunlight.

Weaving Process

The weaving process began with preparing corset patterns and weaving the corset in smaller sections. Once the weaving was complete, the hems were double-knotted and cleaned up by tucking individual yarns into the interior of the corset. The sections were then pieced together by hand-sewing the seams with Lyocell threads. Finer details requiring intricate needlework were also hand-sewn with Lyocell threads.

The corset was adjusted on a dressmaker's mannequin and fastened with hook and eye tape. Lastly, kombucha boning was added. A total of nine boning strips were hand-sewn along each seam connecting one section to another. The kombucha boning was created by weaving thin strips of kombucha threads in a plain weave.

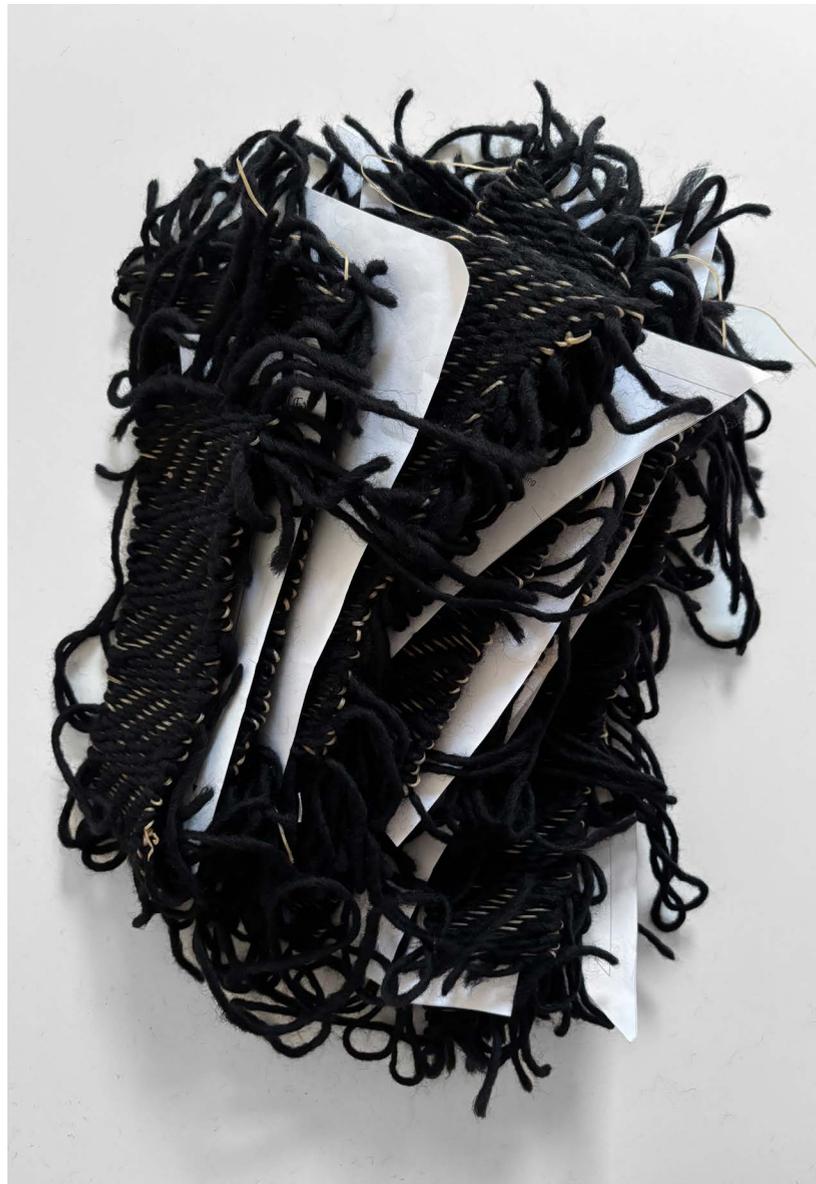
The final step involved adding kombucha "petals" to the corset. This was done by rehydrating the tips of kombucha threads in water for a few minutes, allowing them to return to their initial wet state. As they expanded and softened, petals were carefully unraveled by hand. Green Lyocell thread was first used to position the petals symmetrically before attaching them to the corset. In total, 51 kombucha petals were used.



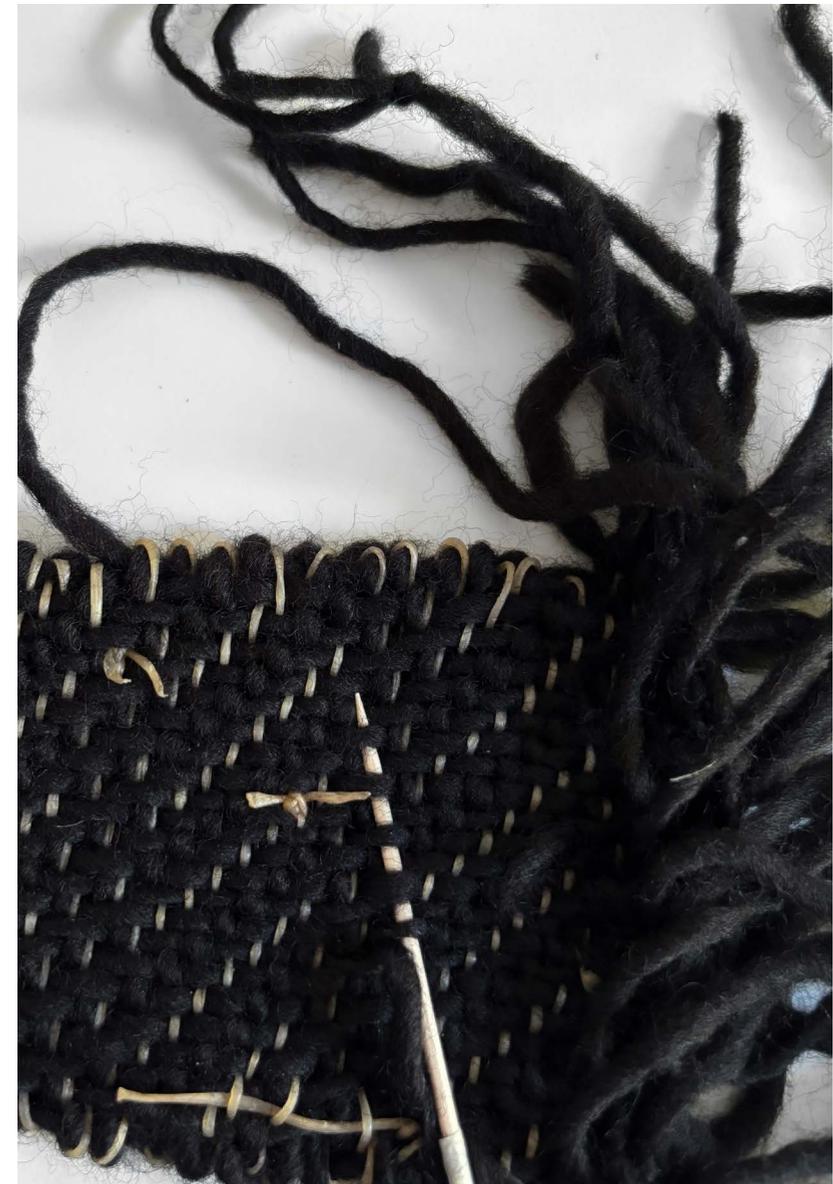
Corset patterns



Corset weaving process



All corset components woven



Hems and seams finished by knotting and tucking into the corset interior



Corset assembled by handsewn seams



Corset boning woven with kombucha threads



Making of kombucha 'petals' for corset embellishment



Kombucha 'petals'



Testing placement of kombucha 'petals' on corset



Lyocell threads mark placement for kombucha 'petals'

Refinements

The design of the corset required several adjustments and refinements. The kombucha boning was completely removed as it did not serve its intended purpose. This might have been due to insufficient meticulous hand-sewing needed to keep it secure and in place, or perhaps the weaving technique and warp/weft direction used did not create a rigid enough structure to hold it against the body, allowing it to bend with any body movement due to its flexibility.

Despite this, the corset still maintained a good amount of structure from the inclusion of kombucha threads. The garment felt sturdy and supportive yet soft and comfortable to wear because of the wool. Additionally, the connecting seams were cleaned up for a more seamless finish by hand-sewing the same wool yarn through them. This created an impression of boning with the yarn slightly protruding from the surface, enhancing the overall finish and durability as well as support.



Seams prior to yarn-looping



Yarn-looping applied to clean up seams



Kombucha boning handsewn onto corset







KOMBUCHA X 80% MERINO WOOL / TWILL WEAVE

KOMBUCHA X 80% MERINO WOOL / 20% SILK / PLAIN WEAVE

02



KOMBUCHA X 80% MERINO WOOL / 20% SILK
PLAIN WEAVE

Conclusion

This research demonstrates the potential of biopolyester, produced from kombucha bacterial cellulose and wheat starch, to reshape the fashion supply chain. With polyester projected to dominate future fiber production, the need for bio-based alternatives grows. This work addresses key environmental concerns—microplastic pollution, carbon emissions, and landfill waste—while integrating design, material science, and circularity to ensure full biodegradability.

A key achievement was the successful use of wheat starch as an alternative carbon source in kombucha fermentation, showing that quality bio-based textiles can be developed without conventional ingredients. Transforming kombucha pellicles into threads proved that natural, biodegradable materials can be shaped into textile forms. Experiments with hydration control and natural dyes, such as hibiscus, identified critical factors for thread strength, while brittleness revealed areas for future development.

The residency phase expanded on this by exploring weaving techniques. Kombucha threads, combined with 100% wool yarn, provided sufficient structural integrity in corsets, eliminating the need for synthetic boning while ensuring durability and comfort. By addressing comfort and adaptability in design, this research advocates for bio-based solutions that balance aesthetics with structural integrity.

Afterword

As this research draws to a close, it marks both a starting point for continued exploration in bio-based materials and regenerative fashion practices. What began as a thesis on biopolyester and kombucha bacterial cellulose evolved significantly during the residency, bridging the gap between theory and practice. Working within the Biolab at Anhalt University facilitated a deep dive into the challenges and potential of kombucha threads—an endeavor that demanded hands-on experimentation, patience, and resilience.

The residency phase allowed for a deeper exploration of kombucha's interaction with natural fibers like wool in garment construction. Creating a woven corset sustained by kombucha threads instead of synthetic boning demonstrated the viability of bio-based materials in functional design. This phase revealed the complexities of working with kombucha threads, such as managing fragility, hydration, and dye stability. The insights gained will guide future studies on the compatibility of kombucha with different fibers and its resilience in diverse applications.

Looking ahead, this work may inspire further research at the intersection of food science, material science, and fashion. Future studies will ideally move beyond the laboratory to assess biodegradability and longevity in natural environments, advancing the understanding of bio-materials in real-world contexts. The ultimate vision is for kombucha threads and similar materials to become integral to a regenerative textile economy—one where fashion harmonizes with ecosystems, enabling both innovation and restoration.

About Collaboration

Vanessa Song is a designer focused on the interaction of regenerative materials and fashion. Her work emphasizes the need for circular alternatives in material selection for garment construction, particularly in light of the environmental challenges posed by conventional fibers like polyester. Vanessa seeks to create apparel that not only captivates but also embodies a commitment to longevity and ecological responsibility. Through her studies, Vanessa became intrigued by the relationship between materials, science, and their environmental impacts. This perspective led her to engage deeply with the potential of natural materials, particularly kombucha threads, in creating functional and expressive textiles.

Collaboration with the Materiability Research Group, particularly at their Biolab, has enriched this research journey. Under the supervision of Prof. Dr. Manuel Kretzer and Virginia Binsch, the research extended into a residency, where she was encouraged to explore the practicalities of kombucha threads as a bio-based textile thread. This experience has fostered a rich exchange of ideas, deepening her understanding of the regenerative potential of materials in the systems they operate in.

With contributions and support from the Materiability Research Group, emphasizing interdisciplinary innovation at the intersection of materials, design, and technology. The group provided theoretical and practical guidance, access to infrastructure and labs, as well as tools, machines, and materials to facilitate this research.

Materiability was established in 2010 as part of Prof. Dr. Manuel Kretzer's doctoral research at the Chair for CAAD, ETH Zürich, with the aim of bridging the gaps between design, architecture, and science. Since then, it has grown into an international community engaged in research and education across materials science, interaction design, textile design, product design, engineering, and robotics. In 2020, Prof. Dr. Kretzer, in collaboration with Virginia Binsch, founded the Materiability Research Group and its associated labs at Anhalt University in Dessau. The group focuses on innovative material fabrication in conjunction with digital design and production processes, emphasizing adaptive technologies and biological materials and their implications for future environments.

With a shared interest in regenerative materials and transformative design solutions, Vanessa Song joined Materiability Research Group as a researcher in residency in March 2024. Building on her research, Vanessa continues to explore the potential and viability of kombucha threads as a bio-based textile thread. Driven by a commitment to regenerative materials and circular design practices, her work seeks to redefine material selection in fashion design, fostering a future that balances both creativity and environmental responsibility.

References

ARMEDANGELS. (n.d.). *We are here to make a Change, not Fashion*. <https://www.armedangels.com/>

Bioplastics Magazine. (2015). *Virent BioformPX paraxylene used for world's first 100% plant-based pet plastic bottle*. <https://www.bioplasticsmagazine.com/en/news/meldungen/20150608Virent-at-basis-of-biosourced-PlantBottle.php>

Birla Cellulose. (n.d.). *A trusted name in Viscose Staple Fibre, MMF*. <https://birlacellulose.com/>

Cao, P., Wu, G., Yao, Z., Wang, Z., Li, E., Yu, S., Liu, Q., Gilbert, R. G., & Li, S. (2022). Effects of amylose and amylopectin molecular structures on starch electrospinning. *Carbohydrate Polymers*, 296, 119959. <https://doi.org/10.1016/j.carbpol.2022.119959>

Cernansky, R. (2021, October 18). Why destroying products is still an “Everest of a problem” for fashion. *Vogue Business*. <https://www.voguebusiness.com/sustainability/why-destroying-products-is-still-an-everest-of-a-problem-for-fashion>

Chen, X., Memon, H. A., Wang, Y., Marriam, I., & Tebyetekerwa, M. (2021). Circular economy and sustainability of the clothing and textile industry. *Materials Circular Economy*, 3(1). <https://doi.org/10.1007/s42824-021-00026-2>

Common Objective (2018). *Viscose And Its Impact*. <https://www.commonobjective.co/article/viscose-and-its-impact>

Dornbirn GFC. (n.d.). *Home*. <https://www.dornbirn-gfc.com/de/>

Dove, S. (2011, September 28). China losing its factory of the world to Bangladesh? *Ecotextile News*. <https://www.ecotextile.com/2023052530735/materials-production-news/bio-based-sythetic-fibres-did-not-degrade.html#%E2%80%8C>

Elkady, N. (2021). *Microbial Leather: The Feasibility of Bacterial Cellulose Composites as Alternative Bio-textiles* (Master's thesis). Hochschule Anhalt, Germany.

Ellen MacArthur Foundation. (n.d.). *How to build a circular economy*. <https://www.ellenmacarthurfoundation.org/>

Esposti, M. D., Morselli, D., Fava, F., Bertin, L., Cavani, F., Viaggi, D., & Fabbri, P. (2021). The role of biotechnology in the transition from plastics to bioplastics: an opportunity to reconnect global growth with sustainability. *FEBS Open Bio*, 11(4), 967-983. <https://doi.org/10.1002/2211-5463.13119>

European Parliament. (n.d.-a). *The impact of textile production and waste on the environment (infographics) | Topics*. <https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics>

Everra. (2025, March 5). *Global Fiber Supply Chain Solutions | Reliable & Sustainable*. <https://steinfibers.com/environment/>

Evrnu. (n.d.). *Nucycl® by Evrnu*. <https://www.evrnu.com/nucycl>

Fashioning Circuits. (2014, March 18). *Sustainable fashion: Kombucha as Couture*. <https://fashioningcircuits.com/?p=2127>

HM. (n.d.). *Recycling System 'Loop' Helps H&M Transform Unwanted Garments into New Fashion Favourites*. <https://about.hm.com/news/general-news-2020/recycling-system-loop-helps-h-m-transform-unwanted-garments-i.html>

Kołodziejczyk, A. (2021). Bacterial cellulose: multipurpose biodegradable robust nanomaterial. In *IntechOpen eBooks*. <https://doi.org/10.5772/intechopen.98880>

Kwon, T. A., Choo, H. J., & Kim, Y. (2019). Why do we feel bored with our clothing and where does it end up? *International Journal of Consumer Studies*, 44(1), 1-13. <https://doi.org/10.1111/ijcs.12540>

Lackner, M. (2022). Third-Generation biofuels: bacteria and algae for better yield and sustainability. In *Springer eBooks* (pp. 1947-1986). https://doi.org/10.1007/978-3-030-72579-2_90

Makarov, I. S., Golova, L. K., Vinogradov, M. I., Levin, I. S., Gromovykh, T. I., Arkharova, N. A., & Kulichikhin, V. G. (2019). Cellulose Fibers from Solutions of Bacterial Cellulose in N-Methylmorpholine N-Oxide. *Fibre Chemistry*, 51(3), 175-181. <https://doi.org/10.1007/s10692-019-10069-6>

Materiom. (n.d.). *What do we mean by “regenerative” materials?* <https://resources.materiom.org/article/what-do-we-mean-by-regenerative-materials/>

Modern synthesis. (n.d.). <https://www.modernsynthesis.com/legal#faqs>

MUD Jeans. (n.d.). *Lease a jeans*. <https://mudjeans.de/pages/lease-a-jeans>

Nanollose. (n.d.). *Nullarbor*. <https://nanollose.com/products/nullarbor/>

Napper, I. E., & Thompson, R. C. (2016). Release of synthetic microplastic plastic fibres from domestic washing machines: Effects of fabric type and washing conditions. *Marine Pollution Bulletin*, 112(1-2), 39-45. <https://doi.org/10.1016/j.marpolbul.2016.09.025>

NatureWorks (n.d.). *Home*. <https://www.natureworkslc.com/>

Oberlo (n.d.). *Apparel Industry Statistics (2018-2028)*. <https://www.oberlo.com/statistics/apparel-industry-statistics>

OceanSafe (n.d.). *Circular Textile Technology* | NANE. <https://www.oceansafe.co/textile-materials/nanea>

Popa, L., Ghica, M. V., Tudoroiu, E., Ionescu, D., & Dinu-Pîrvu, C. (2022). Bacterial Cellulose—A remarkable polymer as a source for biomaterials tailoring. *Materials*, 15(3), 1054. <https://doi.org/10.3390/ma15031054>

RadiciGroup. (n.d.). *Polyamide PA6 textile yarn, Repetable®*. <https://www.radicigroup.com/en/products/fibres-and-nw/repetable>

Robertson, L. (2024, February 12). Material Guide: *What is Viscose and Is It Sustainable? - Good On You*. Good on You. <https://goodonyou.eco/material-guide-viscose-sustainability/>

Rosenboom, J., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. *Nature Reviews Materials*, 7(2), 117-137. <https://doi.org/10.1038/s41578-021-00407-8>

Rykkelid, E. (2015, April 18). *Growing products*. Tumblr. <https://growingproducts.tumblr.com/post/116720734816/growing-experimentation-i-started-growing>

Sacha Laurin (n.d.). *Kombucha Couture*. <http://www.kombuchacouture.com/>

ScienceDirect Topics. (2014). Polyester Fiber - an overview. *Sciencedirect.com*. <https://www.sciencedirect.com/topics/chemistry/polyester-fiber>

Stanton, A. (2025, April 10). *What is fast fashion, anyway?* The Good Trade. <https://www.thegoodtrade.com/features/what-is-fast-fashion/>

Tapias, Y. a. R., Di Monte, M. V., Peltzer, M. A., & Salvay, A. G. (2021b). Bacterial cellulose films production by Kombucha symbiotic community cultured on different herbal infusions. *Food Chemistry*, 372, 131346. <https://doi.org/10.1016/j.foodchem.2021.131346>

Team, C. (2023, August 7). *Hartshorn salt and “baking” solves a serious environmental problem*. <https://science.ku.dk/english/press/news/2023/hartshorn-salt-and-baking-solves-a-serious-environmental-problem/>

Teijin (2023). *Teijin Frontier Facilitates Recycling of Discarded Polyester Apparel with Novel Technology for Removing Polyurethane Elastomer Fiber*. https://www.teijin.com/news/2023/04/10/20230410_01.pdf

Textile Exchange. (n.d.). *Preferred Fiber and Materials Market Report 2022 (2024a, September 26)*. <https://textileexchange.org/knowledge-center/reports/materials-market-report-2022/>

The North Face (2022). *The North Face Renewed Take-Back*. Retrieved January 2, 2024, from <https://www.thenorthface.com/en-ca/approach/the-north-face-renewed-take-back>

The Reformation (n.d.). *RefRecycling | Clothing & Shoe recycling*. <https://www.thereformation.com/sustainability/ref-recycling.html>

The Versatility and Comfort of Cotton Polyester Blend Fabric. (n.d.). *Langka*. Retrieved January 2, 2024, from <https://langka.group/blogs/langka-blogs/the-versatility-and-comfort-of-cotton-polyester-blend-fabric>

United Nations Climate Change. (2018, January 22). Fashion Industry, UN Pursue Climate Action for Sustainable Development. *UNFCCC.int*. <https://unfccc.int/news/fashion-industry-un-pursue-climate-action-for-sustainable-development>

United Nations Environment Programme. (n.d.). *Cleaning up couture: what's in your jeans?* UNEP. <https://www.unep.org/news-and-stories/story/cleaning-couture-whats-your-jeans>

Zhang, S., Xu, C., Xie, R., Yu, H., Sun, M., & Li, F. (2022). Environmental assessment of fabric wet processing from gate-to-gate perspective: Comparative study of weaving and materials. *The Science of the Total Environment*, 857, 159495. <https://doi.org/10.1016/j.scitotenv.2022.159495>

Zhao, X., Wang, Y., Chen, X., Yu, X., Li, W., Zhang, S., Meng, X., Zhao, Z., Dong, T., Anderson, A., Aiyedun, A., Li, Y., Webb, E., Wu, Z., Kunc, V., Ragauskas, A., Ozcan, S., & Zhu, H. (2023). Sustainable bioplastics derived from renewable natural resources for food packaging. *Matter*, 6(1), 97-127. <https://doi.org/10.1016/j.matt.2022.11.006>

Credits

Manuel Kretzer	Research supervisor Folio editor
Virginia Binsch	Research supervisor
Philip Beesley	Folio editor
Adrian Chiu	Folio editor
Materiability (MRG)	Biolab facility provider
Sagar Vanapalli	Tensile strength testing supervisor
Christian Pfütze	Tensile strength testing supervisor
Madeira	Sensa® Green Lyocell provider
Sophia Reichelt	Model for thesis
Saskia Lüdecke	Model for residency
Uwe Jacobshagen	Photography supervisor
Paulina Schröder	Photography supervisor

Image Credits

All images included in this folio were taken by the author, Vanessa Song, Anhalt University, 2023-2024.