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A Study on Possibility of Biomaterial in Fashion Product Design -focusing on experiment of fruit peels-

패션 제품 디자인에서 바이오 소재의 가능성에 관한 연구 - 과일껍질 실험을 중심으로 -

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차례

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ABSTRACT

In recent years, biomaterials, as a new type of material, have been recognized as an effective solution to the environmental challenges facing the fashion industry due to their non-polluting and biodegradable properties. While many biomaterials are now in commercial production, they are difficult to access by small studios or individuals. This is mainly due to undisclosed commercial formulations and high production costs. Moreover, there is little documentation on biomaterial production processes, limited to a few personal blogs or specific open source websites. Therefore, the aim of this study is to provide a concise and practical methodology for studio-scale experiments so that biomaterials can be fabricated on a personal level. In terms of research methodology, the definition and scope of biomaterials were first investigated, and examples of bio-based and peel-based materials were analyzed to determine their characteristics and limitations. Next, experiments were conducted using fruit peels and materials readily available in daily life, and the test product were directly fabricated to investigate their potential as biomaterial. The experiment has two main directions: Firstly, the effects of binders, glycerol and preservatives (salt, lemon) were explored. Secondly, the effect of the original color of the fruit peel on the material color was experimented, and the visual effect of varying the thickness and the particle size of the material. In addition, drying experiments were conducted to observe the effect of the drying process on the material properties. Finally, four different designs of pouches and a garments were made based on the experimental results, demonstrating the potential of fruit peels as biomaterials. It is hoped that this study can lead to more active research on biomaterials and expand their uses, further promoting the integration and application of biomaterials in daily life.

Keywords
biobased material
fruit peel
sustainability
biomaterials

요약

최근 몇 년 동안 바이오 소재는 무공해, 생분해성, 신소재로서 패션 업계가 직면한 환경 문제에 대한 효과적인 해결책으로 인정받고 있다. 현재 수많은 바이오 소재가 상업적으로 널리 사용되고 있지만, 소규모 스튜디오나 개인적인 차원에서 접근하기는 어렵다. 이는 주로 공개되지 않은 상업적 배합과 높은 생산 비용 때문이다. 또한, 바이오 소재를 만드는 과정을 자세히 다룬 논문은 부족하며 개인 블로그나 특정 오픈소스 웹사이트에 국한되어 있다. 이에 이번 연구의 목적은 개인적 차원에서 바이오 소재를 생산할 수 있는 스튜디오 규모의 실험을 위한 간결하고 실용적인 접근 방식을 캡슐화하는 것이다. 이를 위한 연구 방법으로는 첫째, 이론적 배경으로 바이오 소재에 대한 정의와 범위를 알아보고, 바이오 기반 소재와 과일 껍질 기반 소재의 사례를 분석하여 그 특성과 한계를 파악하였다. 둘째, 일상생활에서 쉽게 구할 수 있는 과일 껍질과 재료를 이용하여 실험을 진행하였고, 그 결과물로 바이오 소재로서의 가능성을 알아보기 위해 직접 시제품을 제작하였다. 실험은 크게 다음의 두 방향을 기준으로 진행하였다. 첫째로 바인더, 글리세롤, 방부제(소금, 레몬)에 대한 실험을 진행하였다. 둘째로, 과일 껍질 고유의 색이 색상에 미치는 영향과 재료의 두께와 분쇄 크기에 따른 시각적 효과 그리고 건조 공정이 재료에 미치는 영향을 관찰하기 위한 건조 실험을 진행하였다. 마지막으로 이러한 실험 결과를 활용하여 네 가지 디자인의 파우치와 옷을 제작하였으며 이를 통해 과일 껍질의 바이오 소재로서의 가능성을 확인할 수 있었다. 이번 연구를 계기로 바이오 소재에 관한 더욱 활발한 연구와 저변 확대가 이루어지길 기대해 본다.

중심어
바이오 기반 소재
과일 껍질
지속가능성
바이오 소재

1. Introduction

1.1 . Research background and objectives

The development of science and technology brings rich material civilizations to human beings, but also damages the living environment to some extent. In recent years, a concerted effort has been undertaken by researchers and designers to mitigate environmental impact through the creation of eco-friendly and biodegradable materials. Biomaterials can effectively reduce resource consumption by recycling waste, and can be produced using solely biotechnology and synthetic biology methods without using massive crops or animal cruelty. Furthermore, biomaterials are now recognized as a promising solution to the environmental challenges confronting the fashion industry. While many biomaterials are now commercially mature, they are not readily available to the general public who want to try them for themselves. The main reason for this is that many commercial formulations are not publicly available and are quite expensive to produce. Moreover, the literature on biomaterial production is scarce and only a few examples can be found. For instance, Bell Fione et al. (2020) presented a method for making bioplastic-Alganyl based on existing DIY recipes, and Jayachandra et al. (2022) used simple laboratory techniques to produce bioplastic film from orange peels. Existing literature introduces a number of biomaterial production techniques and potential applications, but no experimental comparisons or more detailed investigations have been carried out. Most information on biomaterial production is limited to personal blogs or specific open source websites. Conducting small-scale personal experiments and methods could enhance the availability of biomaterials on an individual workshop level, contributing to the expansion of this field. Therefore, the objective of this study is to explore the potential of fruit peels as biomaterials through experiments utilizing fruit peels and readily available materials commonly found in people's daily lives. Based on the results, prototypes are developed to showcase the possibilities of this biomaterial.

1.2. Research method

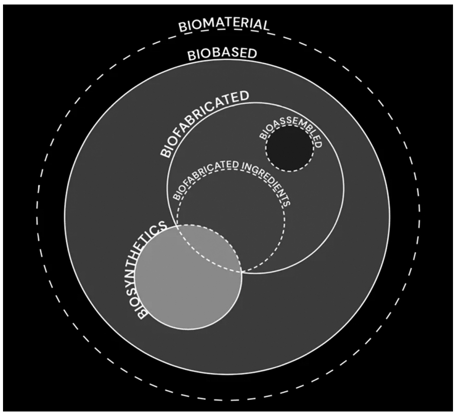
In this study, the theoretical background of biomaterials is first outlined. Subsequently, different types of biomaterials are analyzed, and their potential for further development is assessed. This study focuses on biobased and fruit peel-based materials, summarizing and analyzing them in terms of morphological features and production methods to understand their properties and limitations. Specifically, experiments and prototyping are conducted using hand-collected fruit peels with two main objectives. Firstly, a study is conducted on the most commonly used food binders and two of them are selected for experiments. Additionally, other additives like glycerin, salt, and lemon are included in the experiments. This is to see how these materials affect the overall properties of the material, not just the binder. Next, the effect of the inherent color of the peel on the final material color is also tested, as well as the visual effect of varying the thickness and the particle size of the material. In addition, drying experiments are conducted to observe the effect of the drying process on the material. Finally, the results of these experiments are utilized to create four different designs of pouches and a garment that demonstrate the originality of this material and its potential for real-life applications.

2. Theoretical background

2.1. Definition of biomaterials

Biomaterial is a very broad term indicating materials that have non-specific biological association. The development of biomaterials stems from advances in biotechnology, which is originally developed for the fabrication of biological tissues, such as skin and organs for medical purposes (Mironov et al., 2009). According to a report (Lee et al., 2020) published by Biofabricate and Fashion For Good in 2020, as shown in <Figure 1>, biomaterials can be subdivided into the following five categories:

• Biobased materials include everything from conventional as well as non animal "leather" that contain fruit or vegetable waste combined with synthetic polymers, and a pure cotton fabric or indeed a polyester cotton mix. All biomaterials inherently possess a biobased nature, although the degree of biobased content varies significantly based on biological constituents. Additionally, the term "biobased" can aptly apply to a substantial portion of biosynthetic, biofabricated, or bioassembled materials.



〈Figure 1〉 *A Set of Biomaterial Terms Representng Key Material Technologies Beging Practiced Today.*

• Biosynthetic materials encompass synthetic polymeric substances that are either entirely or partially composed of compounds derived from biological sources. These compounds can be generated using inputs of biological origin, achieved through the conversion of biomass, or through processes facilitated by living microorganisms.

• Biofabricated materials only include microbially produced building blocks for both "natural" and "synthetic" polymers, such as silk and nylon.

• Biofabricated ingredients encompass building blocks that are generated by living cells and microorganisms. These ingredients necessitate subsequent mechanical or chemical processing to attain their final form. Notably, this category includes intricate proteins such as silk or collagen.

• Bioassembled materials are exclusively derived from living cells, including those of mammals, and microorganisms like bacteria, mycelium, and fungi.

2.2. Case on biobased materials

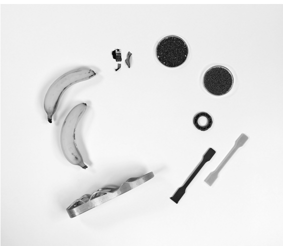
Biobased renewable materials have a longstanding tradition in fashion history. However, with the widespread industrialization and globalization of the sector, even materials of natural origin do not guarantee sustainability. Although biobased materials can contribute to reduced greenhouse gas (GHG) emissions, their production still demands a significant amount of water and land (Zhao et al., 2021). In contrast, materials synthesized from fruit or vegetable wastes and other biobased materials circumvent the need for cultivating arable land and the use of pesticides or harmful chemicals in their manufacturing. Moreover, they are petroleum-free, biodegradable, and have minimal environmental impact, thus preventing pollution to the greatest extent possible. Biomaterials find applications across various fields, from fashion to household products. In the next four cases focusing on biobased materials, this study scrutinizes the properties and methods

〈Figure 2〉 *Bioplastic Sheets Dress*

of biomaterials for each project. Additionally, an evaluation is conducted from the resource cycle perspective to assess their potential for future recycling, as well as their aesthetic impact.

Designer Phillip Lim collaborated with Charlotte McCurdy to create a sea green, petroleum-free dress that symbolizes the deconstruction and reconstruction of marine ecosystems <Figure 2>. This dress is made of algae, which are fused together under high heat and poured into a custom mold. After cooling, the bioplastic sheets are cut into shiny pieces, which are then sewn onto a fishing-net-like mesh made from seaweed and bamboo fiber called SeaCell, produced by natural textile suppliers PYRATEX. At present, the design functions exclusively as a "concept dress" and has not yet been incorporated into a business strategy. Nonetheless, it presents a vision and outlook for an emission-free future.

Unprocessed food waste is known to have a significant environmental impact, prompting designers to perceive organic waste as a source of valuable raw materials to be experimented with to develop new textiles (Collet, C., 2018). Currently, a notable trend involves the conversion of food waste into biomaterials, including materials derived from sources like shrimp peel, orange peel, and used coffee powder (Pavlovic et al., 2013). Swiss designer Sarah Harbarth has transformed banana peels into a new compostable material product-KUORI. By amalgamating recycled polylactic acid (PLA) material with banana peels, she has created 3D printed filaments <Figure 3>. The banana peel 3D printed soles, replacing traditional plastic microplastics ones, prevent the detrimental dispersion of microplastics into soil and water due to abrasion. Furthermore, the designer has created banana peel eyeglass frames and banana peel watch straps as sustainable alternatives to plastic eyeglass frames and leather straps. The designer created products by recycling local food waste, providing a solution for non-recyclable and compostable disposal. While the resulting product can indeed be composted at the end of its lifespan, PLA has limited inherent degradation capabilities. Consequently, the product, which combines banana peel and PLA, requires specialized processing after its intended use.



〈Figure 3〉 *KUORI Banana Product.*

Currently, many material companies and designers are actively exploring the potential of fruit peels. For example, textile designer Youyang Song developed PEELSPHERE, a biodegradable and circular material made from fruit waste and algae <Figure 4>. PEELSPHERE is a malleable and waterproof textile that can be embroidered, woven, and knitted to create infinite patterns, and it can also be used as an alternative to real and synthetic leather. Moreover, depending on its use, it can harden to create a protective case, or turn soft to create a handbag.

〈Figure 4〉 *PEELSPHERE Tote.*

In addition, Berlin design students Lobke Beckfeld and Johanna Hehemeyer-Cürten have developed a translucent fruit-leather bag Sonnet155 <Figure 5>. This groundbreaking accessory is ingeniously crafted from a fusion of two distinct post-industrial waste components. The first comprises fruit skins leftover from juice production, while the second incorporates short cellulose fibers sourced from a local textile factory. The material uses pectin extracted from the cell walls of fruit peels as a natural binder. Although Sonnet155 resembles a tote, its lifespan is closer to a disposable paper bag and is designed to naturally degrade with wear and tear before eventual composting or recycling.

Previous studies have shown that biomaterial development not only requires specialized

〈Figure 5〉 *Sonneet155 Fruit-Leather Bag*

technical equipment, but also has strict requirements for the production environment, and the cost is high. For instance, expenses associated with gathering, transporting, and cleaning materials like pineapple leaves and orange peels, along with the need for disinfection, labor input, and adhesive extraction, contribute to the elevated costs incurred in the production of biological fabrics. Furthermore, the production cycle of biomaterials is often protracted due to their intricate nature. These challenges are further exacerbated by the unavailability of proprietary commercial formulations, the limited range of online resources for open source recipes, and the lack of comprehensive experimental results. Based on the aforementioned case studies, the aim of this paper is to explore the potential of crafting biomaterials at a personal level. To this end, experiments were conducted using fruit peels to test their viability of being made into materials. Test products were then made from these materials to demonstrate their value and usefulness.

3. Fruit peel experiments and test product

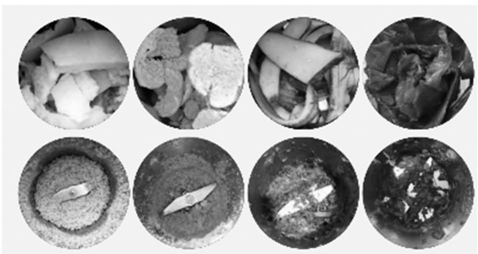
3.1. Experimental outline

Throughout our daily lives, a constant stream of refuse is generated, with household waste accounting for a substantial portion. Most organic waste is typically disposed of through landfilling, incineration, and composting. If not handled properly, these practices can cause a lot of problems for the environment. Utilizing household waste as raw materials for biomaterials offers the potential to address a portion of this waste problem at its root. Hence, fruit peels, which are common waste in our daily life, are chosen for this paper to investigate their potential as biomaterials.

To begin, the study focuses on fruit peels that are readily available in daily life and often discarded as waste, aligning with the recycling perspective. The second aim is to make use of the inherent natural color of the peels without the requirement of additional dyeing. The third is to assess the durability and resilience of the peel as a material for products. Lastly, the study aims to investigate the potential deterioration or moldy of the fruit peels material and assess its overall sustainability.

3.2. Experimental materials and tools

Before conducting the experiment, the initial step involved selecting the type of fruit peel. For this study, commonly discarded fruit peels from everyday life were chosen, including banana peel, orange peel, grapefruit peel, and dragon fruit peel <Figure 6>. These four types of fruit peels were selected due to their availability and the variation in their colors, which can offer a wider range of color options for the resulting material. The collected fruit peels were stored in airtight containers and placed in a refrigerator at a temperature of approximately 8°C until they were ready for use. It is important to note that since most fruit peels are prone to oxidation, prolonged storage is not recommended.



〈Figure 6〉 *From Left to Right: Grapefruit Peel, Orange Peel, Banana Peel, and Dragon Fruit Peel.*

According to the previous case, extracting pectin from fruit skin requires complex steps and techniques. As an alternative, existing binders can be used in place of pectin. After conducting a survey, several commonly used natural binders were identified: gelatin,

〈Figure 7〉 *Four Natural Adhesives. (https://en.wikipedia.org/wiki)*

sodium alginate, agar, and carrageenan <Figure 7>. Here are the properties of these four binder: Gelatin is derived from animal bones, which can result in a subtle fishy smell. Before use, it should be pre−soaked in cold water to allow for water absorption and expansion. Afterwards, it needs to be heated and stirred well until completely dissolved. Sodium alginate is a natural gum extracted from brown algae, which dissolves slowly in water and should be stirred for around 20 minutes or used in a blender. Solidification of sodium alginate requires mixing with sodium chloride. Agar and carrageenan are vegetable gums derived from seaweed that possess the advantage of rapid solidification at room temperature. Additionally, they exhibit remarkable elasticity and can form thermally reversible gels. Since it is not feasible to test all available binders, the experiments primarily concentrated on agar and carrageenan as the main binder. This is because they have reliable curing characteristics and are compatible with a wide range of mixed peels. Other additives used in the experiment include glycerol, which can alter the softness of the material. It is worth noting that when using food as a raw material, the surface of the fabric may become moldy due to the weather influences. To prevent mold growth, salt and lemon were also added in the experiment. Additionally, experiments were conducted with a blender to break down the fruit peels and a food dryer to dry the material.

3.2. Experimental process and results

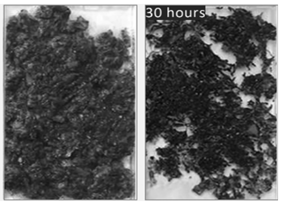
The experiment was conducted using two main methods. The first experiment focused on the effect of adhesives and glycerin on the material, as well as the effect of incorporating preservatives (salt, lemon) to prevent mold formation on the biomaterials. The second experiment aimed to explore color variations by combining different fruit peels and also investigated the difference in transparency resulting from variations in material thickness.

3.3.1. Experiment 1

Firstly, 30 g of ground banana peel, orange peel, grapefruit peel, and dragon fruit peel residues were selected separately for the experiment. For the agar experiment, 4 g of agar powder was added into 60 ml of water, and the mixture was heated while stirring continuously until the agar dissolves. Then, the fruit peel residue was added, followed by a pinch of salt and a few drops of lemon juice. The mixture was stirred until it became very thick, and then poured it into the mold. For the carrageenan experiment, 4 g of carrageenan powder was added into 60 ml of water, and the mixture was poured into a blender and blended for a few minutes. The grated fruit peel was then added and heated, and the mixture was continuously stirred for 5 minutes and incorporated the glycerol. Similarly, a pinch of salt and a few drops of lemon juice were added. In the end, the mixture was poured into the molds until it thickened significantly.

During the experiment, it was observed that prompt and thorough stirring is essential once the adhesive is introduced. Any disruptions in the mixing process or excessive temperatures may lead to the mixture becoming scorched. Upon pouring the mixture into the container, a waiting period of 3 to 5 days is imperative to ensure thorough drying.

Experiments have shown that the use of different binders has little effect on the material. In contrast, the content of glycerol emerged as a critical factor in modifying material toughness. Glycerol was found to enhance material toughness and transparency while reducing brittleness. The samples with the addition of glycerin showed greater flexibility after drying. This experiment also demonstrated that not all fruit peels are suitable for home experiments. For example, banana peels displayed a clear oxidation reaction during the experiment. Their color darkened significantly over time, and ultimately turned black <Figure 8>. As a result, banana peels were excluded from subsequent experiments. It has also been proven through experiments that salt and lemon effectively inhibit the growth of mold. The samples treated with salt and lemon were successfully stored for more than eight months without mold.



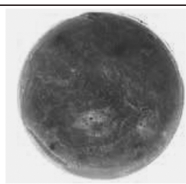
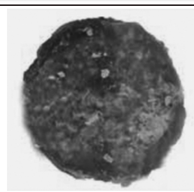
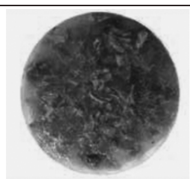
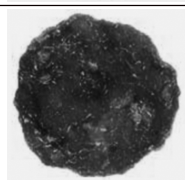
〈Figure 8〉 *Color Change of Banna Peels Material*

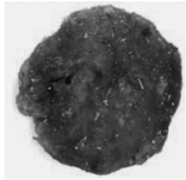
3.3.2. Experiment 2

Experiment 2 primarily focused on comparing colors using individual fruit peel versus mixed fruit peels, aiming to explore the color diversity of the materials. The experiments were conducted with equal-sized containers to ensure controlled analysis of the data. Likewise, the mixture was obtained following the previous experimental procedure, and poured into 100 mm petri dishes. It was then dried in an outdoor dryer and a food dryer, respectively.

The experimental results indicate that blending different colors of fruit peels can enhance the color diversity of the material <Table 1>. Furthermore, a comparison of natural drying and machine drying effects on material color and shape reveals that both methods effectively preserve the original color of the fruit peel. The variation in material shape during outdoor drying was not significant. Although a home dryer considerably shortens the drying time, it can lead to more noticeable changes in size and shape. For optimal preservation of material integrity, natural drying is used in favorable weather conditions, ensuring the quality of the material after demolding.

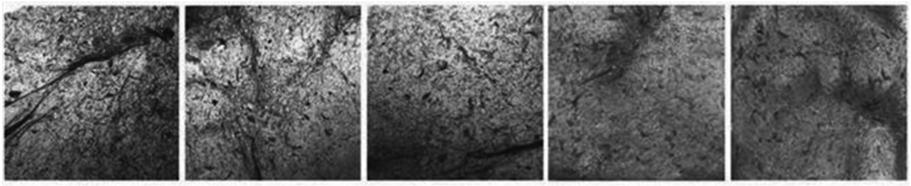
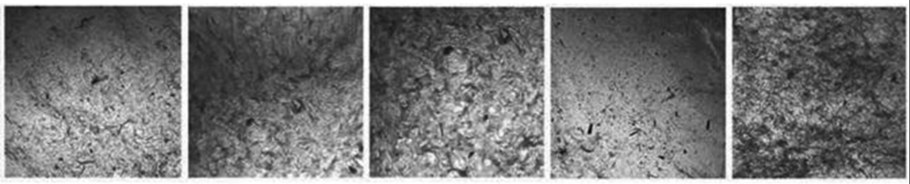
〈Table 1〉 *Includes Experiment 1& Experiment 2 - Comparison of Fruit Peels Experiments*

Experimental subject	Experimental method	Experimental picture	Dehydrating method	Picture after demolding
orange and dragon fruit peel	mix 4 g agar, glycerin with experimental subject, boil, stir and keep it in a natural state		outdoor drying, 96 hours	
dragon fruit peel and grapefruit peel	mix 5 g agar, glycerin with experimental subject, boil, stir and keep it in a natural state		outdoor drying, 96 hours	
dragon fruit peel	mix 4 g agar, glycerin with experimental subject, boil, stir and keep it in a natural state		put it in the drying machine for 6 hours	

grapefruit peel	mix 4 g agar, glycerin with experimental subject, boil, stir and keep it in a natural state		put it in the drying machine for 6 hours	

In reference to <Table 2>, it's noticeable that the material's transparency increases with decreasing thickness, and the depth of color also contributes to this transparency variation. Specifically, the material mixed with dragon fruit and grapefruit peels exhibits a pink color with high transparency; the material with grapefruit peels showcases a yellow hue with high transparency; and the one mixed with dragon fruit, orange, and grapefruit peels has an orange-red color with moderate transparency. In addition, the texture of the material can be altered by controlling the particle size of the peels to enhance its visual and tactile attributes. This produced fruit peels biomaterial demonstrates biodegradability, enabling natural decomposition by microorganisms. Furthermore, it can be dissolved and reconstituted into a new material, realizing its value through recycling.

〈Table 2〉 *Samples of Different Colors, Textures, and Transparency Variations*

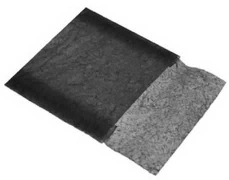
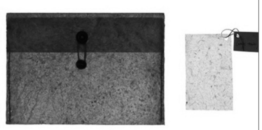
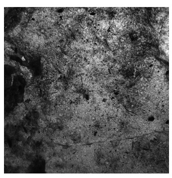
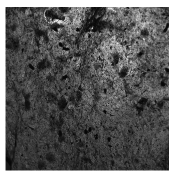
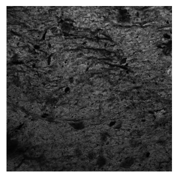
Fruit type	Detail photos	Describe
dragon fruit and grapefruit peel		pink color, transparency varies with material thickness
grapefruit peel		yellow hue with high transparency, color and transparency vary with the amount of peel added
dragon fruit, orange, and grapefruit peel		orange-red color with moderate transparency, different textures depending on the size of the peel particles

3.4. Final test product

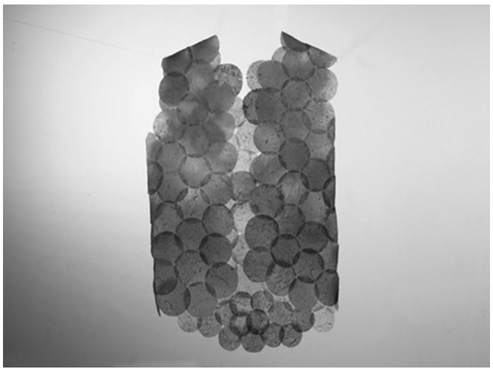
In order to make test products, it is necessary to produce a large area of material. Therefore, on the basis of the above experiments, larger containers are used with the same experimental ratios. For instance, if the target container size for the upcoming experiment is 32 cm*42 cm*3.3 cm, the corresponding quantities would entail 420 ml water, 210 g mixed fruit peel, 28 g agar or carrageenan, and 5 ml glycerol. The thickness of the samples is influenced by the quantity of fruit peel waste introduced into the mixture. Thicker samples resemble leather-like materials, while thinner samples resemble bioplastics. Hence, when producing larger areas of material, the thickness of the material can be varied by changing the ratio of peels to water and the weight of the peels.

In order to better demonstrate the product potential of this material, a series of test products were made from these materials. As shown in <Table 3>, design 1 is made from a blend of dragon fruit, grapefruit and orange peels. The material sample is relatively soft with medium thickness and not easy to tear. This ingenious design circumvents traditional sewing methods, involves cutting and folding the material to achieve the desired form. Design 2 further shows a folder-style bag made from grapefruit and orange peels. Samples used for design 2 are soft and thinner, so sewing should be done carefully. To create this bag, the material is first cutted to the desired size. The whole bag is then assembled using basic hand sewing techniques. Design 3 and Design 4 showcase designs crafted from a combination of dragon fruit and orange peels. These pieces utilize thicker and more durable material samples, creating a texture similar to leather. To enhance their functionality, zippers have been seamlessly incorporated into the design to ensure ease of use. These four pouches, made from fruit peel biomaterials, fulfill the same purposes as conventional fabric pouches and can be used in everyday life. Because this fruit peel biomaterial is tough and thick, it is also very good at resisting wear and tear. When it has been used for too long to be usable, it can be simply dissolved in warm water to make a new one of the same quality.

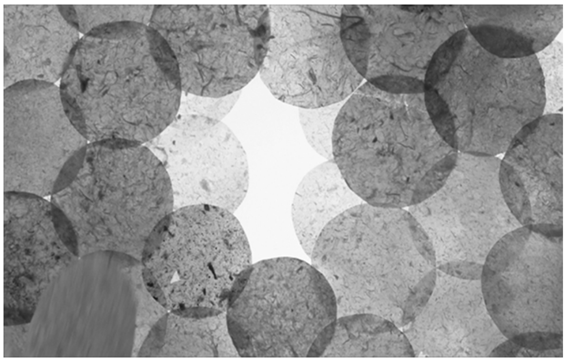
〈Table 3〉 *Descriptions of Design and Production Method*

Design features	Design1	Design2	Design3	Design4
Image				
Size (unit: cm)	13*13.5	26*19	19*10	20*15
Experimental subject	dragon fruit, grapefruit, and orange peel	grapefruit and orange peel	orange and dragon fruit peel	dragon fruit peel
Experimental material	420 ml water, 210 g fruit peel, 28 g carrageenan lota and 5 ml glycerol	630 ml water, 315 g mixed fruit peel, 40 g carrageenan lota and 8 ml glycerol	420 ml water, 210 g mixed fruit peel, 28 g agar and 5 ml glycerol	420 ml water, 210 g mixed fruit peel, 28 g agar and 5 ml glycerol
Detail photos				
Production methods	no sewing, sliced and folded	hand-sewn, attached with buttons	hand-sewn, equipped with zippers	hand-sewn, equipped with zippers
Material softness & Durability	relatively soft with medium thickness, not easy to tear	soft and thin, sewing should be done carefully	relatively hard and thick, similar to leather, not easy to tear	harder and thicker, similar to leather, not easy to tear

In addition, the material also holds potential for clothing applications. While not yet fully wearable, as shown in <Figure 9>, it demonstrates the potential of the material to some extent. These pieces can also be connected using natural binder as depicted in <Figure 10>. The garments are composed of various fruit peel materials, resulting in a gradient effect. Despite being in the early stages of development, the material's potential for clothing can already be seen.



〈Figure 9〉 *Clothes Made from Fruit Peels Waste*



〈Figure 10〉 *Biomaterial Pieces Detail Photo*

5. Conclusion

This research explored the properties of biomaterials and produced a series of test products using waste fruit peel materials. Through the analysis of biobased material cases, the study focused on repurposing commonly discarded fruit peels. In contrast to existing fruit peel products, the findings can be summarized as follows:

Firstly, the use of food waste from daily life for biomaterial production eliminates the need for energy intensive and costly recycling processes typically undertaken in factories. This approach offers a convenient and cost−effective method for small−scale production and personal experimentation. Second, although biomaterials are increasingly being recognized, products made from biomaterials are still in the developmental stage for various reasons. By enabling individuals to craft their own fruit peel products, this approach promotes sustainability, reduces household waste, and empowers consumers to actively embrace environmentally conscious practices. Thirdly, a resource recycling method is employed by utilizing 100% fruit peels with natural binder, allowing for the products to be recycled even after reaching the end of their lifespan. Through recycling, redesign, and remanufacturing, the material follows a close loop system, extending its utility and realizing its full potential. However, it's important to acknowledge that this study does have limitations. For instance, the biomaterial products created have a lengthy production cycle and are susceptible to weather conditions. While efforts were made to experiment with various fruit peel colors and alter the material's texture by controlling the particle size of the peels, a comprehensive exploration of material morphology remains lacking. Nonetheless, as a study on biomaterials, it holds significance. By showcasing the potential of fruit peel materials, it is hoped that greater interest and active exploration of biomaterials will be stimulated.

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