Textile & Leather Review

ISSN 2623-6281 | www.tlr-journal.com | 10.31881/TLR

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How to cite: Liu L, Daoruang K, Sankaburanurak A. Preparation and Characterization of Bio-Fibre Based on the Biological Properties of Bougainvillaea, Loofah, and Aloe Vera. Textile & Leather Review. 2024; 7:1377-1400. https://doi.org/10.31881/TLR.2024.159

How to link: https://doi.org/10.31881/TLR.2024.159

Published: 26 November 2024

Preparation and Characterization of Bio-Fibre Based on the Biological Properties of Bougainvillaea, Loofah, and Aloe Vera

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Article

https://doi.org/10.31881/TLR.2024.159

Received 5 October 2024; Accepted 13 November 2024; Published 26 November 2024

ABSTRACT

This study is based on environmental sustainability and aims to explore the preparation and evaluation of biodegradable bio-fibre materials using discarded bougainvillaea, loofah, and aloe. After sorting and analyzing the existing literature, it is found that research on bougainvillaea, loofah, and aloe primarily focuses on environmental science, horticulture, biology, light industry, and pharmacy, while research on bio-fabric combining bougainvillaea, loofah, and aloe in two or three combinations remains unexamined. This study adopts both observational and experimental methods to identify candidate varieties suitable for natural dyeing by observing the characteristics of bougainvillaea and by preparing and testing bio-fibre materials through experimentation. Notably, the beet pigment found in bougainvillaea serves as a natural dye, the α-cellulose and hemicellulose in loofah sponge provide strong hydrophilicity, and the caffeic acid and rhamnolipids in aloe exhibit antioxidant and antibacterial properties, thereby improving the fabric's safety. Experimental results and final bio fibre performance tests indicate that fibres made from these three plants have a stable internal structure, abrasion resistance of over 30,000 cycles, colour fastness concentrated at level 4, and a contact angle of less than 90°, thereby showing good stability, abrasion resistance, colour fastness, and hydrophilicity. Consequently, this study finds that bio-fibres prepared from bougainvillaea, loofah, and aloe demonstrate promising performance and are expected to contribute to the development of sustainable fibres in the future.

KEYWORDS

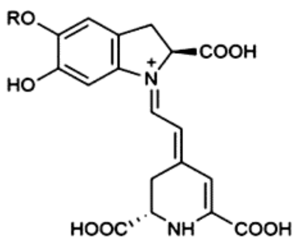
biodegradable fibre, green production, bougainvillaea, loofah, aloe vera

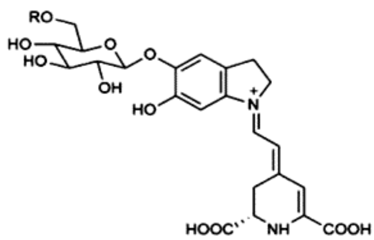
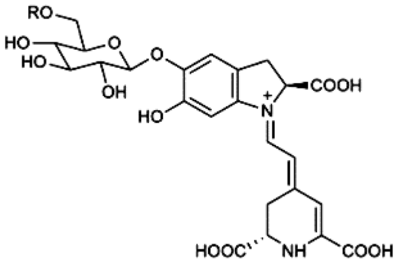
INTRODUCTION

In the context of economic globalization, the textile industry has a profound impact on the global economy and environment. At present, with the increasing awareness of green consumption, the focus of manufacturers, buyers and consumers is shifting to environmentally friendly and durable textile options [1]. This has accelerated the growth of demand for green textiles and promoted the industry's transformation towards sustainability. At present, natural dyes from plant, animal or mineral sources are becoming a good alternative to synthetic dyes because they are both environmentally friendly and sustainable [2,3,4]. At this time, the innovative application of bio-fibre, such as the reuse of waste plants (bougainvillaea, loofah and aloe vera), provides new ideas for textile design. These materials are biodegradable, non-toxic and antibacterial, which not only reduces environmental pollution but also promotes the sustainable development of the textile industry. Therefore, this study hopes to prepare safe and pollution-free bio-fibres from waste plant materials to promote the development of green textiles.

The Bougainvillaea plant is characterized by its branches, leaves, flowers, and distinctive bracts, which are often mistaken for flowers due to their vibrant colours and unique shapes. The colourful bracts serve as ornamental parts, wrapping around the true sepals and flower organs. These bracts are rich in betalain pigments, including betalain red and betalain yellow, which present promising opportunities for developing safe natural food pigments. Betalains, water-soluble pigments similar to anthocyanins, are derived from betaine aldehyde and various amino acids, and their structural details can be summarized in Table 1 [5,6,7,8]. Phytochemical screening by Shalini M et al. confirmed the presence of flavonoids, tannins, steroids, and triterpenes in Bougainvillaea bracts, further establishing their antioxidant potential through in vitro tests [9]. The abundance of betalain pigments not only enhances sustainability in textile dyeing but also aligns with ethical sourcing and circular economy principles [10]. Additionally, Bougainvillaea's applications in green synthesis and nanotechnology have garnered research interest. Notable studies include the green synthesis of TiO2 nanoparticles using Bougainvillaea flower extract, which highlights the reduced environmental impact and costs [11]. Furthermore, the microwave-assisted green synthesis of gold nanoparticles from Bougainvillaea leaf extract exhibited excellent antibacterial properties [12], while Bougainvillaea flower extract has been successfully utilized as a green reducing agent in the reduction of graphene oxide, demonstrating significant performance in sensing applications [13].

Table 1. Molecular structure of betalain pigment from bougainvillaea bracts

Structure	R group	Reference
	R = H R = Glc	Khan and Giridhar, 2015

	R = H R = Malonyl	AlardL et al., 1985
	R = p-Coumaroyl R = Feruloyl	Wybraniec and Nowak-Wydra, 2007

Loofah, with its natural fibre structure and high porosity, is widely used in household cleaning, medical care, textiles, and agriculture. As a chemical-free cleaning tool, it's ideal for scrubbing kitchenware and bathrooms. Medically, loofah promotes blood circulation, reduces inflammation, and is used in traditional Chinese medicine. Its breathable, eco-friendly fibres are also valued in textiles and agriculture for antibacterial and adsorptive properties, supporting sustainable practices. Structurally, a loofah is a mesh of multi-layered fibre bundles, typically with 3-4 cavities comprising the outer wall, cavity, and core. Composed mainly of α-cellulose and hemicellulose, loofah fibres are highly hydrophilic, enhancing fabric comfort and ecological adaptability. Researchers have developed loofah cellulose membranes via a top-down method, demonstrating excellent oil-water separation, cost-effectiveness, and renewability. Additionally, loofah-based superhydrophobic materials created through sol-gel methods show high water contact angles for efficient, low-cost oil-water separation [14,15]. Loofah materials offer strong adsorption, breathability, antibacterial qualities, sweat resistance, and tensile strength [16].

Aloe vera has short stems, thick, toothed leaves, and diverse shapes. Using modern spectroscopic analysis, caffeic acid and emodin can be isolated from aloe. Caffeic acid provides antioxidant protection for fabrics, extending their lifespan, while emodin offers antibacterial effects to keep fabrics clean. Together, these properties enhance fibre safety, extend textile life, and reduce resource waste. In composite studies, aloe vera fibre filled with 3 wt.% chitosan shows excellent mechanical and thermal properties [17]. Composites of silane-treated aloe fibre with pistachio shell powder-reinforced epoxy resin demonstrate improved load-bearing and fatigue resistance [18] Laminates with different epoxy grades show notable differences in strength and bending resistance [19]. In textiles, aloe vera liquid has antistatic properties, suitable as a fabric finishing aid. Aloe fibre, rich in amino acids and polysaccharides, is ideal for underwear and bedding. Aloe can also be blended to enhance fabric functions. As a mordant, aloe extract improves dye fastness and offers antibacterial, moisturizing, UV protection, and radiation shielding effects, broadening its textile applications [20,21]. Wang Yanlai et al. demonstrated that aloe peel used as a natural dye provides silk with colour fastness and UV protection [22].

In sustainable textile research, reducing waste and promoting reuse and recycling are key goals for developing eco-friendly materials [23]. This study harnesses the natural properties of discarded bougainvillaea, loofah, and Aloe vera to produce biodegradable bio-fibres with hydrophilicity, colour fastness, and fabric safety, offering an efficient and sustainable solution for green textile development.

OBSERVATION

By observing different varieties of bougainvillaea in the Xiamen Botanical Garden, we systematically sorted out their morphological and colour characteristics and selected samples for later dyeing experiments. Throughout the process, we combined the opinions of botanical experts to make judgments and selections. Bougainvillaea varieties are extremely rich, and the characteristics of flower bracts are generally straight, broad and oval, with blunt tips and heart-shaped bases. When analyzing the structural characteristics of Elizabeth Angus Bougainvillaea, it can be found that the branches of this Bougainvillaea usually grow 3 flowers in clusters, and each flower has a bract. The three perianths in the cyme inflorescence open asynchronously, the upper part of the perianth is usually 5 flatly lobed, and the pedicel is attached to the midrib of the bract. The leaves of this Bougainvillaea are glossy and the veins are clear. The perianth contains the perianth tube, ovary, ovules, ovary stalk, stamens and style brushes (Figure 1).

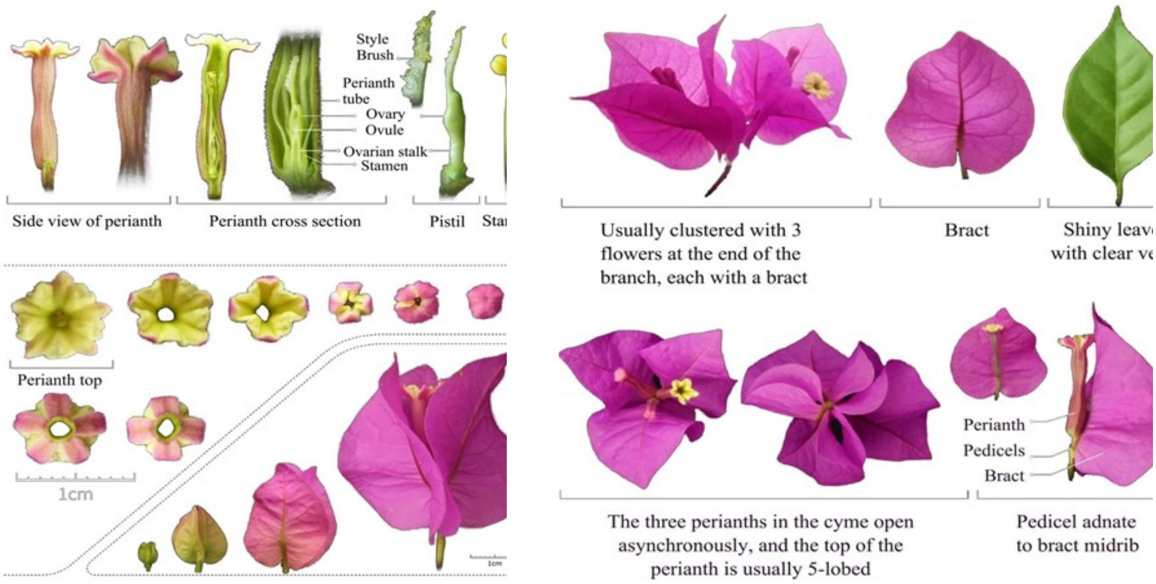


Figure 1. Structural characteristics of Bougainvillaea

According to the colour of the bracts, they can be roughly divided into the following seven categories. The varieties of bougainvillaea with different colours are shown in Table 2.

Red series: such as double-petaled red bougainvillaea, the characteristics are red bracts, sometimes double petals, and rich flower colours.

Pink series: such as cherry bougainvillaea, the colour is light at first bloom and deepens with time, with a sense of layering.

Yellow Series: such as lemon yellow bougainvillaea, the colours are uniform and very bright, and look particularly attractive.

Orange series: such as green-leaf orange bougainvillaea, its characteristics are orange-red bracts and green leaves, and the colour is bright and vivid.

Purple series: such as the light purple bougainvillaea, the bracts are light purple, the flowers are small and the colours are elegant.

Green series: such as green cherry bougainvillaea, the initial flower colour is light green, and later gradually changes to white with red, which is unique and rare.

White series: such as silver leaf white bougainvillaea, with silver patterned leaves and pure white bracts, it looks fresh and elegant.

Table 2. Names and colours of seven colour systems of Bougainvillaea

Colour Series	Name	Picture	Bud colour
Red series	Klong Fire		bright red
	Miss Manila		watermelon pink
Pink series	Sakura		light pink
	Aruna		rose pink

Colour Series	Name	Picture	Bud colour
Yellow series	Golden Glow		yellow
	California Gold		golden yellow
Orange series	Orange Glory		orange-red
	Orangish		orange-yellow
Purple series	Mariel Fitzpatrick		light purple
	Makris		white and purple striped
	Sao Paulo		bright purple
Green series	Green Cherry		light green

Colour Series	Name	Picture	Bud colour
Green series	Green Apple		light yellow-green
White series	Silver Leaf White		White
	Spray some new white		bright white

EXPERIMENTAL

Materials and Methods

This study uses experimental methods to explore the dyeing properties, sustainability, and textile performance of bougainvillaea, loofah, and aloe vera as bio-fabric materials. Among them, fibre extraction is the first step in studying bougainvillaea, loofah and aloe vera as bio-fabrics, and the processing methods of different materials are also different. The next step is the preparation experiment of bio-fabrics, and finally the performance test of bio-fabrics. The experimental steps in this phase include fibre treatment, preparation of bio-fabric samples, addition of functional ingredients, performance testing and analysis of results.

Material Preparation

1) The freshly fallen bougainvillaea that had just bloomed was washed, and its leaves and flowers w ere removed, leaving only the flower bracts, which were then crushed.
2) The loofah was crushed to obtain loofah powder. Fresh aloe vera was taken, peeled, and its juice was scraped out, followed by filtration to obtain the aloe vera stock solution.
3) Materials were prepared, including purified water, gelatin, glycerin, carrageenan, sodium alginate , calcium chloride, and methylcellulose for use.
4) Basic tools: pot, stirring rod, electronic gram scale, tray, dryer, several measuring cups of differen t sizes, etc.

Basic experimental steps

1) After boiling water in a pot, glycerin was added and stirred, followed by gelatin (or carrageenan, methylcellulose) until it melted completely. Loofah powder, aloe vera stock solution, and crushed bougainvillaea were then added in sequence, and the mixture was stirred for about 2 minutes until the bougainvillaea's colour was fully released. The heat was turned off, and the mixture was left to stand.
2) Once the mixture had settled, the entire solution was poured into a filter to remove any excess re sidue.
3) The filtered solution was carefully poured into a bowl, ensuring that the liquid was poured slowly to avoid creating bubbles, which could affect the final product. After the solution solidified, it wa s removed and placed in a dryer (different material ratios affected the solidification time).
4) Once the dryer had finished drying the material, the basic biological fabric was obtained (varying material ratios caused the drying time to differ).

Preliminary experiment

In the preliminary experiment, six trials were conducted with varying ratios of glycerin, water, gelatin, and bougainvillaea weight, as well as different standing times at room temperature. The goal was to examine the flexibility and formability of the fabric. Results showed that higher glycerin content improved flexibility, but the fabric failed to form in initial trials with increased glycerin. Water ratio also impacted texture: too much water hindered drying, while too little created a viscous solution with bubbles. Combined variations of glycerin and gelatin accelerated solution melting at room temperature, preventing fabric formation. Using dyed "Bilas" bougainvillaea, the final material was water-red, retaining bougainvillaea bract texture (Figure 2). The inability to mould may be due to high humidity, insufficient cellulose, or incomplete biological materials. A new round of experiments will refine these steps for improved stability and moldability.

Figure 2. "Bilas" staining

RESULTS AND DISCUSSION

Effect of carrageenan and methylcellulose on the moulding of fibre materials

Combining the results of preliminary experiments and relevant data feedback, this study introduced carrageenan and methylcellulose as gelling agents and stabilizers in a new round of experiments to improve the moulding probability and stability of biological fabrics. In the first two sets of experiments, the dosage of methylcellulose and carrageenan was set to 1.5 times, and finally, the experimental materials were successfully formed. The third set of experiments increased the volume of water, methylcellulose and carrageenan to 1.5 times that of the first two groups. It was found that the semi-solidification time of this group of materials was 1.5 times slower than that of the first group and slower than that of the second group. 2 times, and the drying time is also extended to twice that of the first two groups, and the final material can also be formed. Based on the success of the first three sets of experiments, the contents of carrageenan and methylcellulose were significantly increased in the fourth set of experiments to further explore the role of these two materials in biofabrics. Compared with data 1-3, the material of data 4 shows poor dehydration, resulting in an increase in thickness and significantly enhanced toughness (Table 3).

Table 3. Experimental data

Experimental data	Data 1	Data 2	Data 3	Data 4
Room temperature (°C)	24	24	24	27
Air humidity (%)	78	85	87	88
Water (ml)	500	500	750	700
Bougainvillaea (g)	10	10	10	20
Loofah powder (g)	2	2	2	5
aloe liquid (g)	10	10	10	30

Experimental data	Data 1	Data 2	Data 3	Data 4
Glycerin (g)	4	4	4	4
Gelatin (g)	5	5	5	5
Methylcellulose (g)	12	18	30	140
Carrageenan (g)	10	15	23	100
Room temperature standing time (h)	0.4 (Semi-solidified)	0.3 (Semi-solidified)	0.6 (Semi-solidified)	48
Drying time of dryer (h)	16	16	32	15
The drying temperature of the dryer (°C)	45	45	45	45
Variable	Methylcellulose, carrageenan		—	—
Moulding	Can be formed	Can be formed	Can be formed	Can be formed, but too hard and poor softness

Effect of solution filtration degree on the performance of biological fabrics

During the experiment, considering the effect of solution filtration degree on the performance of biological fabrics, including thickness, smoothness, toughness and colour depth, solution filtration was divided into three levels: full filtration, half filtration and no filtration. At the same time, according to the performance of thickness, smoothness, toughness and colour depth, they were divided into three levels, with the strongest being marked as 3, the second being 2, and the weakest being 1. Materials with different filtration levels were placed in a dryer and dried at the same temperature and time. The results showed that the thickness level was no filtration, half filtration and full filtration from high to low; the smoothness level was full filtration, half filtration and no filtration from high to low; the toughness level was full filtration, half filtration and no filtration from high to low; the colour depth level was no filtration, half filtration and full filtration from high to low (Table 4). The bougainvillaea used for dyeing this time was the "Bilas" variety, the same as that used in the previous pre-experiment, and its overall colour was rich and water red. The L*a*b* differences before and after the three filtration degree materials are formed are mostly concentrated between 2-3. The colour difference between the materials can be slightly clearly distinguished, but relatively speaking, the colour difference is not very obvious. At the same time, the Lab values of the full filtration, half filtration and non-filtration materials show a gradual decrease.

Table 4. Differences in the different property levels of bio-fabrics

Category	Full filtration	Semi-filtration	No Filter
Before molding			
After molding			
Thickness	1	2	3
Smoothness	3	2	1
Toughness	3	2	1
Colour Depth	1	2	3
	L*：50.12-51.37	L*：41.98-42.38	L*：33.72-35.69
L*a*b*	a*：17.39-20.15	a*：27.14-28.95	a*：24.37-28.93
	b*：19.47-23.59	b*：21.85-22.68	b*：19.68-24.35

Effects of yarn and wool on bio-fabric properties in controlled experiments

To explore diverse textures in biological fabrics and provide creative material sources for future products, this study included two sets of controlled experiments. In the basic operation, yarn and wool were added to assess their effects on enhancing the hardness and appearance of the biofabric. Additionally, to evaluate the impact of aloe vera solution dosage on fabric moulding, control group 1 was established with specific variables (Table 5). Results indicated that adding yarn increased stiffness and produced a matte surface, while the yarn-free material was softer with a glossy finish. The amount of loofah powder in control group 1 was tripled to 6g compared to previous experiments, resulting in significantly improved toughness and more pronounced brown colouration. In terms of aloe vera stock solution usage, 30 g was added to data 1 of control group 1, while data 2 had none. The bio-fabric formed in data 1 felt softer and more skin-friendly, whereas data 2 had a poorer hand feel and lower skin-friendly properties. For the dyeing experiment, the "Makris" variety of bougainvillaea was selected, featuring lighter colours (white and purple) in its bracts. Due to the large amount of brown loofah powder used, the dyeing effect of "Makris" was minimal (Figure 3).

Table 5. Control experiment data

NO.	Control variables/conditions	Control group 1		Control group 2	
		Data 1	Data 2	Data 1	Data 2
1	Room temperature (°C)	27	27	32	32
2	Air humidity (%)	89	89	76	76
3	Pure water (ml)	650	650	300	300
4	Bougainvillaea (g)	20	20	20	20
5	Loofah powder (g)	6	6	2	2
6	aloe stock solution (g)	30	0	20	20
7	Glycerin (g)	100	100	30	30
8	Methylcellulose (g)	140	140	15	15
9	Carrageenan	—	—	15	15
10	Drying time in the dryer (h)	20	20	—	—
11	Drying temperature in dryer (°C)	50	50	—	—
12	Stationary time (h)	—	—	72	72
13	Whether it contains yarn/wool	No	Yes	No	Yes
14	Variables	aloe liquid, yarn		Wool	
15	Moulding situation	Moldable		Moldable	
16	Material characteristics	Shiny and soft	Matte, hard	Smooth and soft	Rich texture, hard

Figure 3. Effect of fabrics in the control group experiment

In Control Group 2, the presence or absence of wool content was used as a variable, and the dyed bougainvillaeas were California Gold and Orange Glory (Table 8 for Control Group 2). The California

Gold dye is golden yellow and the Orange Glory dye is orange red. From experiments, it is known that the surface of the wool-containing fabric is rich in texture and relatively stiff; the wool-free fabric is smoother, thinner, softer, and has a certain gloss on the surface. From left to right, the picture shows California Gold (with wool), California Gold (without wool), Orange Glory (with wool) and Orange Glory (without wool) (Figure 4). At the same time, the softness of the material is also affected by the thickness. The lower the thickness, the softer the fabric.

Figure 4. California Gold and Orange Glory dyeing effects

The role of bougainvillaea, loofah and aloe in bio-fibres

This study comprehensively analyzed the biological characteristics of bougainvillaea, loofah and aloe, selected ingredients suitable for experiments, and further verified the role of these three in bio-fabrics through experiments. In the study, multiple groups of control experiments were designed to control different variables to evaluate the effects of these variables on the moulding of bio-fabrics. Specifically, the first group of control experiments used bougainvillaea bracts as variables; the second group of control experiments used loofah as the design variable; the third group of control experiments used aloe as a variable; the fourth group of control experiments added tulle as a variable; and the fifth group of control experiments explored its effect on bio-fabrics by adding wool. Through the analysis of the data of the above five groups of control experiments, it was concluded that bougainvillaea has a significant dyeing effect, the fibre-containing loofah has stronger toughness, and the fibre-containing aloe is more skin-friendly (Table 6). At the same time, combined with the experimental results, the differences in the effects of different elements on the moulding results of fabrics were further revealed (Figure 5). Among them, the amount of methylcellulose and glycerol content is proportional to the moulding effect of the material within a certain range.

Table 6. Control experiment results

Control group	Variables	Content	Fixed value	Results
Control group 1	bougainvillaea	Yes	loofah, aloe	The colour is close to that of dyed bougainvillaea
		No		The colour is affected by loofah powder and is light brown
Control group 2	loofah	Yes	bougainvillaea, aloe	The fabric is more resilient
		No		The fabric is soft and not easy to shape
Control group 3	aloe	Yes	bougainvillaea, loofah	The fabric is more skin-friendly
		No		The fabric is relatively dry
Control group 4	gauze	Yes	bougainvillaea, loofah, aloe	The fabric is matte and stiff
		No		The fabric is shiny and softer
Control group 5	wool	Yes	bougainvillaea, loofah, aloe	The fabric is rich in texture and more resilient
		No		The fabric is smooth

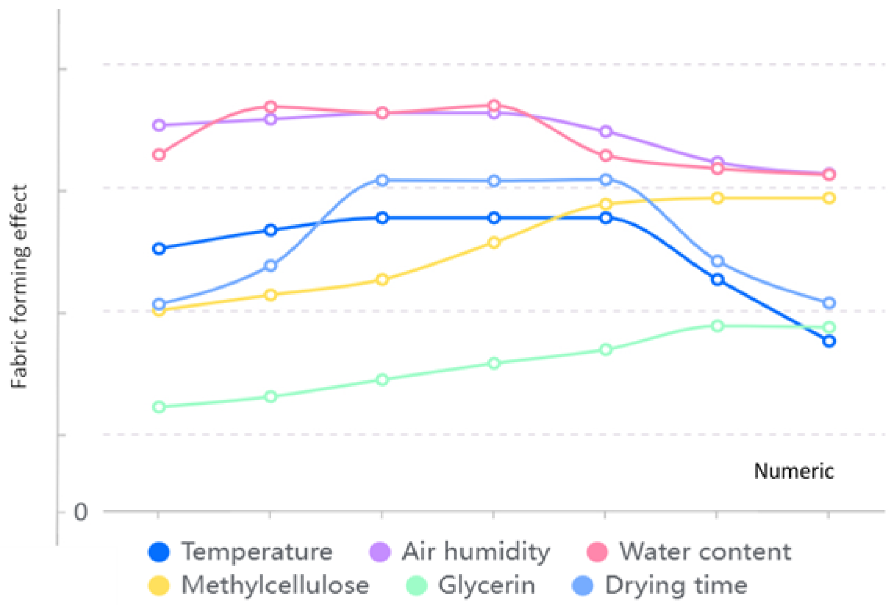
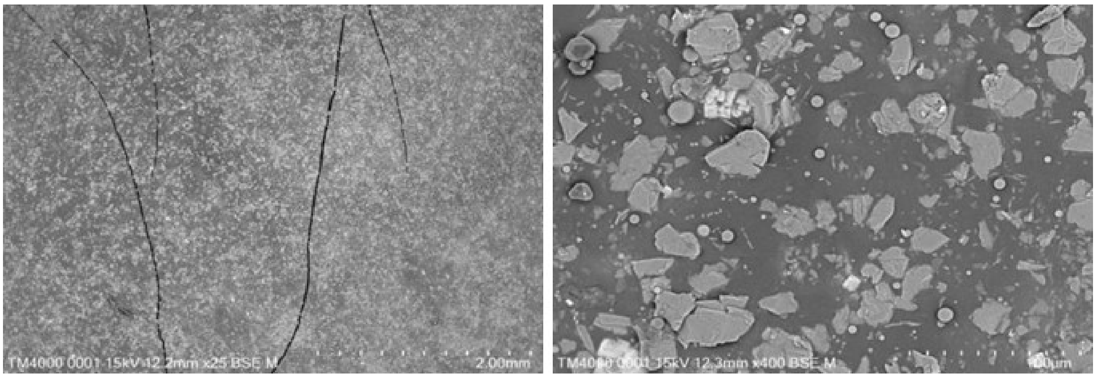


Figure 5. Effects of different elements on Fabric Forming

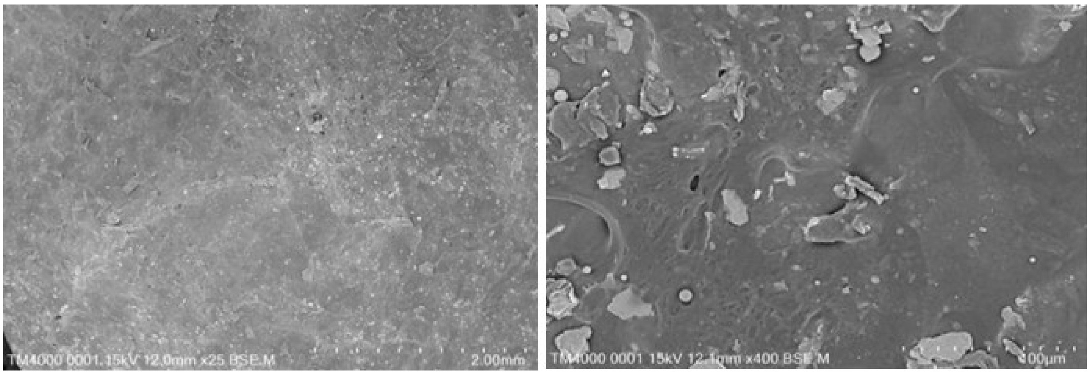
BIO-FIBRE PERFORMANCE TEST

SEM analysis

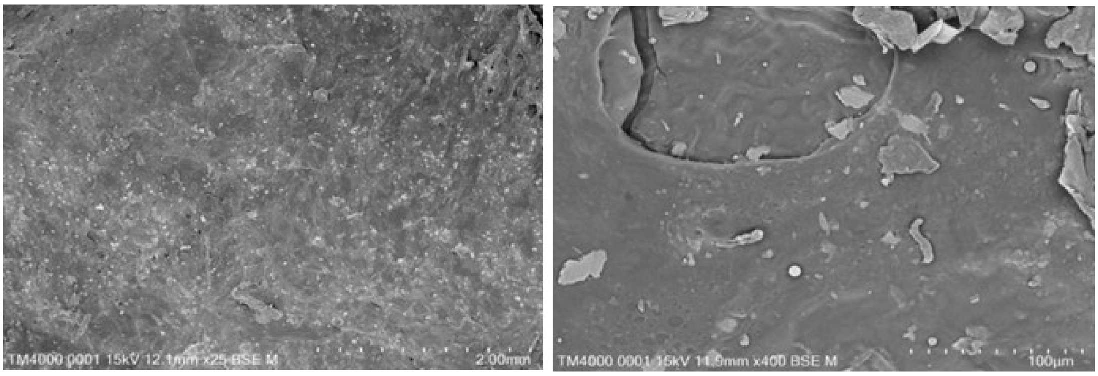
This part of the study utilized a desktop scanning electron microscope (model: Hitachi TM4000Plus) to observe the original morphology of the material and the size of the nanomaterials. Sample preparation involved cutting sections into 2 mm × 1 mm blocks, which were glued to the sample table with electron microscope tape. The samples were then gold-coated to ensure data accuracy. Once prepared, the samples were placed in the sample chamber and vacuumed. Software parameters were set (software: TM4000) with an acceleration voltage of 15 KV, current mode selected as mode 3, and vacuum mode as M. Three types of fabric samples were tested: fully filtered, semi-filtered, and unfiltered, at magnifications of 25 and 400 (Figure 6). High-magnification images revealed uneven surfaces with irregularly shaped particles, small holes, cracks, and bubbles across all samples. At lower magnification, the fully filtered sample showed a more uniform particle distribution and regular shape, while semi-filtered and unfiltered samples exhibited a rugged internal morphology with noticeable gullies. This led to poorer stability and increased susceptibility to tearing in the latter two types.



a) Full filtration SEM image



b) Semi-filtered SEM image



c) Unfiltered SEM image

Figure 6. SEM images of fabric samples

Martindale method (fabric abrasion resistance test)

Wear resistance is a key indicator of textile quality, directly impacting product durability and efficiency. It not only leads to the loss of strength but also affects the fabric's appearance. This section employs the YG (B) 401 Martindale abrasion tester to assess fabric wear resistance. The experimental material and standard abrasive are rubbed against each other using the Lissajous curve motion, with the number of wear cycles before damage used to evaluate wear resistance (Table 7). The Martindale method includes three determination techniques: sample damage, mass loss, and appearance quality change. The sample damage method is favoured for its low error and clear results. This study follows national standard GB/T 21196.2 to assess fabric damage after specific friction counts. For nonwoven fabrics, damage is defined by holes with a diameter ≥0.5 mm.

This experiment examines the wear resistance of materials with different filtration levels. Three parts each of fully filtered, semi-filtered, and unfiltered materials are tested, totalling nine samples, numbered 1-1# to 3-3#. Wear resistance is evaluated based on the number of frictions leading to sample damage. Results indicate that fully filtered material sustains slight damage at approximately 32,500 cycles, semi-filtered at 31,500 cycles, and unfiltered at 30,000 cycles, with the latter showing the most uneven surface texture (Table 7). The consistent friction counts confirm the effectiveness of the experimental method. Ultimately, fully filtered material exhibits higher wear resistance due to its smoother surface, while the mixed biological fabric of bougainvillaea, aloe vera, and loofah demonstrates good wear resistance, making it suitable for general-use environments.

Table 7. Inspection intervals for damage tests

Test series	Expected number of frictions when the sample is damaged / times	Inspection interval/times
0	≤ 2 000	200
a	＞2 000 and ≤ 5 000	1000
b	＞5 000 and ≤ 20 000	2000
c	＞20 000 and ≤ 40 000	5000
d	＞40 000	10000

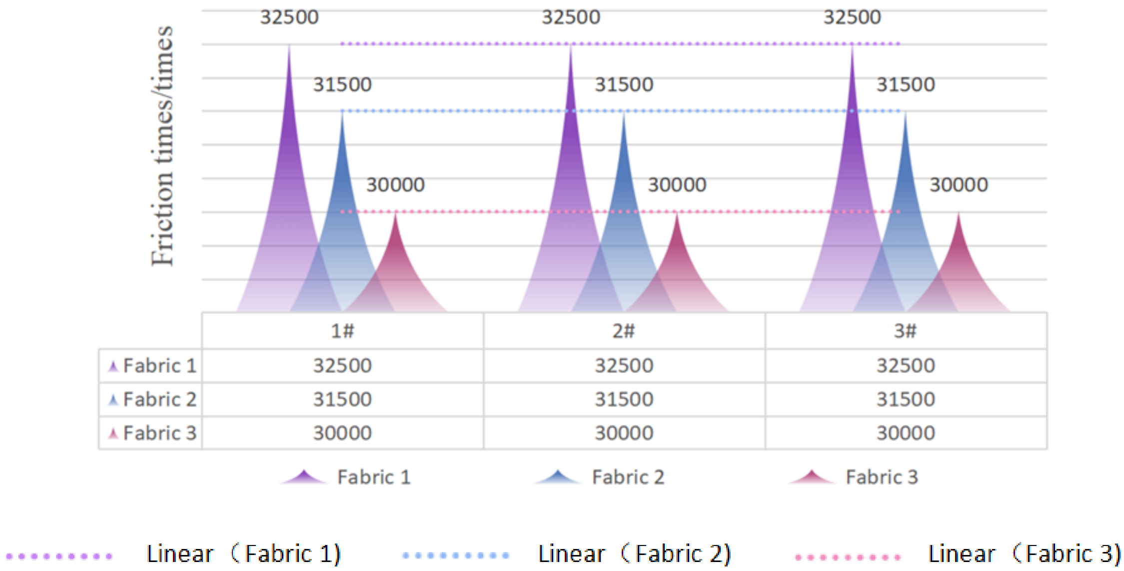


Figure 7. Comparison of friction times of three materials

Colour Fastness to Rubbing

Colour fastness refers to the ability of dyed or printed textile materials to withstand the effects of various factors during textile production and daily use, such as water, light, friction, polyester, perspiration and other common effects. Rubbing colour fastness is the resistance of a textile to colour staining and colour change when rubbed or friction. The results of the rubbing fastness test are evaluated on a grey scale. Textile samples were rubbed with dry and wet rubbing cloths to assess the degree of staining of the rubbing cloths [24]. The colour fastness to rubbing is classified into grades 1 to 5, which indicates the colour fastness condition of different grades of the fabrics, and the higher the value of the grade, the higher the colour fastness of the fabrics. Different rubbing colour fastness classes are shown in Table 8.

Table 8. Different grades of colour fastness

Grade	Fastness Type	Median
1	Poor	
2	Moderate	1-2
3	Good	2-3
4	Very Good	3-4
5	Excellent	4-5

When testing the friction colour fastness of the bio-fabrics made from bougainvillaea, loofah, and aloe vera, we prepared three samples for each of the three filtration levels: full filtration, half filtration, and unfiltered. This resulted in a total of 9 samples. They were numbered 1-1#, 1-2#, 1-3#, 2-1#, 2-2#, 2-3#, 3-1#, 3-2#, 3-3#, and the intermediate value was marked with 0.5. The number of samples for dry and wet tests was the same. The colour fastness test was carried out using the Y(B)571-111 colour fastness friction instrument, and dry and wet tests were carried out respectively. To ensure the consistency of the test samples, the same sample was tested dry and then wet. The number of frictions for a single test was set to 50 times, 450 times for dry and wet tests, for a total of 900 times. The colour fastness result of No. 2-2# can be seen in the figure below (Figure 8). By comparing with the GB/T251-2008 standard and calculating the average value, it is concluded that the colour fastness level of the wet test is concentrated at level 3, with slight colour fading; the colour fastness level of the dry test is concentrated at level 4-5, with a higher colour fastness level (Figure 9). Overall, the colour fastness level of the wet test is lower than that of the dry test, but the combined colour fastness from both tests is above level 3. Based on the test results, it is evident that the bio-fabric made from the mixture of bougainvillaea, aloe vera, and loofah exhibits higher colour fastness.

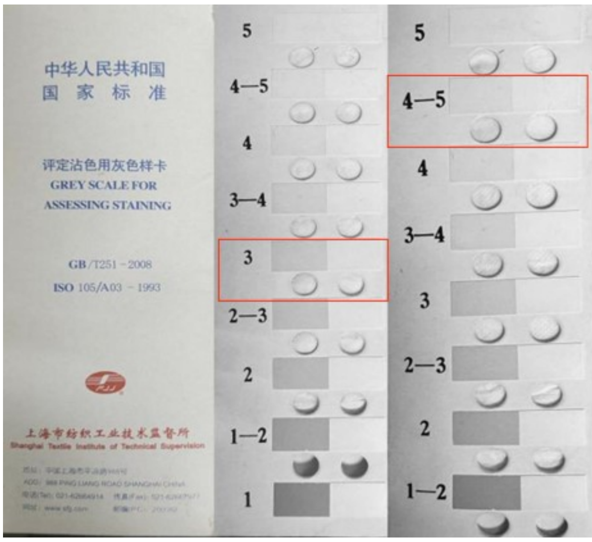
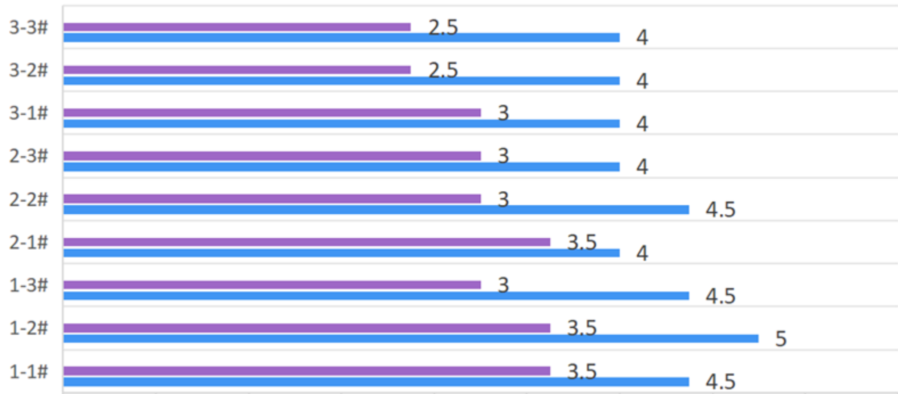


Figure 8. No. 2-2# Wet and Dry Test Data Record



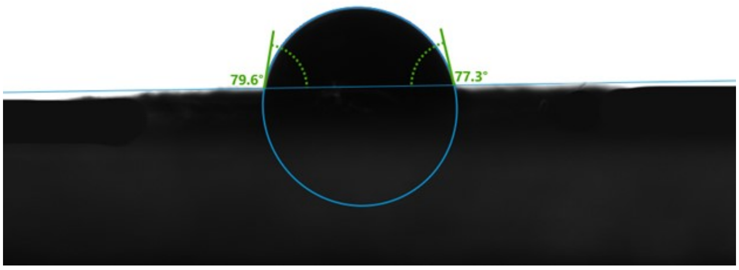
	1-1#	1-2#	1-3#	2-1#	2-2#	2-3#	3-1#	3-2#	3-3#
Wet test	3.5	3.5	3	3.5	3	3	3	2.5	2.5
Dry test	4.5	5	4.5	4	4.5	4	4	4	4

Figure 9. Colour fastness values for dry and wet tests

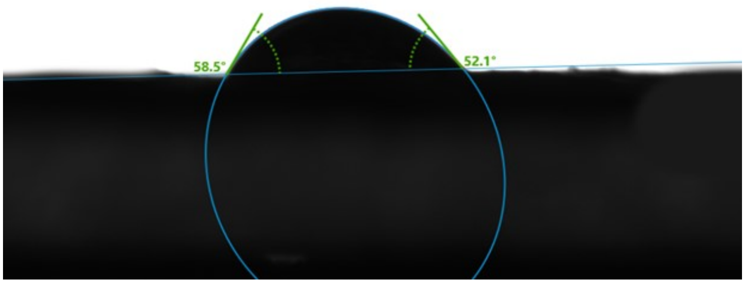
Contact angle test (hydrophilicity test)

At the contact line between liquid, solid, and air, the liquid forms a slope known as the contact angle [25]. Determining solid-gas interfacial tension (γ sv) and solid-liquid interfacial tension (γ sl) is significant in both pure and applied sciences [26]. The contact angle indicates how well a surface is wetted by a liquid: a low contact angle means the liquid spreads easily on the surface, while a high contact angle suggests a liquid-repellent surface. A contact angle of 0° indicates complete wetting; angles between 0° and 90° show that the solid is wettable, with smaller angles indicating better wettability. Angles above 90° mean the solid is non-wettable, allowing the liquid to move easily on the surface without entering pores.

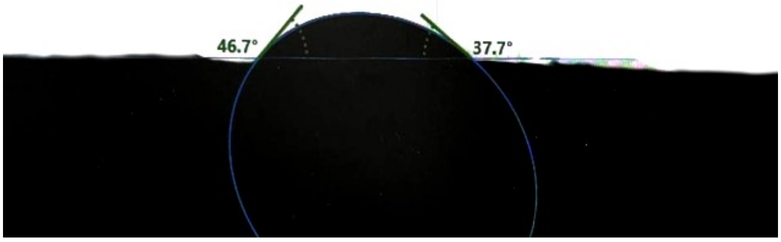
This test employs the sessile drop method, where 5 µL of liquid is placed at the centre of a solid sample. Once the droplet stabilizes, its shape is captured through horizontal photography. Samples must be dry, clean, and free from grease, dust, and stains. The test is conducted at room temperature (25°C) and humidity (70%). The sample is placed flat on a sample table, and an optical contact angle meter measures the wettability of the surface using 5 µL of deionized water. Static contact angles are measured at three different locations on each sample, and the average is calculated. Three samples are prepared for different filtration degrees: full filtration, half filtration, and unfiltered. To measure static contact angles at three locations on each sample, they are numbered 1-1#, 1-2#, 1-3#, 2-1#, 2-2#, 2-3#, 3-1#, 3-2#, 3-3#, yielding a total of 9 data sets. The contact angle data for samples 1-1#, 2-1#, and 3-1# are displayed in Figure 10.



a) Sample No. 1-1#



b) Sample No. 2-1#



c) Sample No. 3-1#

Figure 10. Contact angle data of three groups of samples

In the test data, the contact angle of the same sample records both the left contact angle and the right contact angle and calculates the single average (the value is retained to one decimal place). The contact angles of 3 different positions of the same sample are counted and then the overall average is calculated to obtain the final average contact angle value of a certain sample. According to the test results, it can be seen that the overall average contact angle of the full filter material sample 1 is 80.2, the overall average contact angle of the half filter material sample 2 is 58.4, and the overall average contact angle of the unfiltered material sample 3 is 46.5. The contact angle decreases with the increase of the surface roughness of the sample (Table 9).

Table 9. The average contact angle of samples

Serial number	θ（L）	θ（R）	Single item average	Overall average
1-1#	79.6	77.3	78.5	
1-2#	82.1	76.3	79.2	80.2
1-3#	80.2	85.6	82.9	
2-1#	58.5	52.1	55.3	
2-2#	65.3	58.9	62.1	58.4
2-3#	54.2	55.3	57.8	
3-1#	46.7	37.7	42.2	
3-2#	52.3	51.6	52.5	46.5
3-3#	48.2	41.5	44.9	

According to the Wenzel equation, the relationship between surface roughness and wettability can be clarified, and the formula is as follows:

$$\cos \theta r = r\cos \theta \tag{1}$$

θ is the equilibrium contact angle of a droplet on a smooth surface, θr is the contact angle of a surface with a larger roughness made of the same material, and r is the roughness factor. The equation shows that if the surface is hydrophilic (θ < 90°), increasing the surface roughness will reduce the surface contact angle; if the surface is hydrophobic (θ > 90°), increasing the surface roughness will increase the surface contact angle [27]. In this experimental study, the final average contact angles of the three groups of samples ranged from 46.5° to 80.2°, all of which were below 90°. The surface roughness of the fully filtered material increased compared to that of the unfiltered sample, resulting in progressively lower contact angles. Comprehensive test data show that deionized water has good wettability on the surface of the experimental sample, indicating that the surface is hydrophilic. Textiles made of hydrophilic fibres can promptly dissipate the water vapour discharged by the human body, making the wearer feel comfortable without the unpleasant feeling of stuffiness and air tightness. Hydrophilic fibres are also often used in blends with hydrophobic synthetic fibres to improve the wearability of synthetic fibres.

CONCLUSION

This study screened cellulose materials for biological fabric preparation. After preliminary experiments with various celluloses, glycerin and methylcellulose were selected for their ability to enhance the moulding of biological fabrics. The results showed that factors like temperature, air humidity, water content, glycerin-to-methylcellulose ratio, and drying time significantly affect the moulding process. High temperatures or humidity hinder shaping and can lead to mould growth. Increased water content in the solution is also detrimental. Glycerin impacts elasticity, toughness, and transparency, while methylcellulose affects viscosity and stability, improving moulding chances. Excessive drying time increases fabric brittleness, while insufficient drying prevents proper formation.

Performance tests of the biological fabrics revealed that among full filtration, semi-filtration, and no filtration samples, the full filtration material had a smoother internal fibre structure and the best stability. Wear resistance tests showed only slight surface damage to the full filtration material after about 32,500 rubs, indicating the highest wear resistance. In rubbing colour fastness tests, the wet and dry fastness ratings for the full filtration material ranged from 3.5 to 5, while the other samples scored between 2.5 and 4.5, showing superior colour fastness in the full filtration material. Hydrophilicity tests indicated average contact angles between 46.5° and 80.2°, all under 90°. The full filtration material had an average contact angle of 80.2°, demonstrating good wettability.

The study aims to explore the feasibility of creating bio-fibres from waste bougainvillaea, loofah, and aloe vera, providing scientific and technical support for sustainable textile development. Research indicates that through careful cellulose selection and process control, bio-fabrics using glycerin and methylcellulose exhibit excellent formability and physical properties, offering innovative, eco-friendly materials for future clothing design and promoting sustainable development in the textile industry.

Author Contributions

Conceptualization – Daoruang K and Sankaburanurak A; methodology – Liu L， Daoruang K and Sankaburanurak A; formal analysis – Liu L; investigation – Liu L; resources – Liu L; writing-original draft preparation – Liu L and Sankaburanurak A; writing-review and editing – Liu L， Daoruang K and Sankaburanurak A. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Funding

This research received no external funding.

Acknowledgements

Thanks to the Textile Laboratory of Clothing and Design Faculty, Minjiang University for providing support in testing fibre materials.

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