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Dai Clothing's Antibacterial Fabric Design Innovation

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Article

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ABSTRACT

Systematic research shows that traditional Dai costumes have unique aesthetics but poor antibacterial properties in hot and humid environments, and there is still a lack of antibacterial research on their fabrics. This study used kapok fibre, silver fibre, viscose fibre, and polyester fibre. It used 18tex blended yarn (m (kapok fibre) ∶ m (silver fibre) ∶ m (viscose) ∶ m (polyester)=20 ∶ 10 ∶ 35 ∶ 35) blending technology to test the antibacterial activity of the fabric according to the national standard (China) GB/T 20944.1-2007 (agar diffusion plate method). The fabric formed antibacterial circles of 2.0mm and 2.9mm against Staphylococcus aureus and Escherichia coli and changed the original fabric's poor elasticity, poor wrinkle resistance and wear resistance, and itchy feeling. The innovative integration of Dai costume colours and patterns into fabric design provides scientific support for Dai costume design while exploring new paths for integrating traditional costumes and modern technology, laying a solid foundation for cultural inheritance and development.

KEYWORDS

Dai clothing, antibacterial fabrics, colours and patterns, design innovation

INTRODUCTION

Dai clothing is an important part of Dai culture and contains rich social, cultural, and aesthetic significance, which requires continuous innovation and inheritance. However, the hot and humid climate in Yunnan, China, is prone to breeding bacteria, causing skin and stomach discomfort. Therefore, for the innovation of Dai clothing, it is necessary not only to retain its unique ethnic customs and cultural charm but also to continuously innovate and improve other functionalities such as the development of functional antibacterial fabrics and style design.

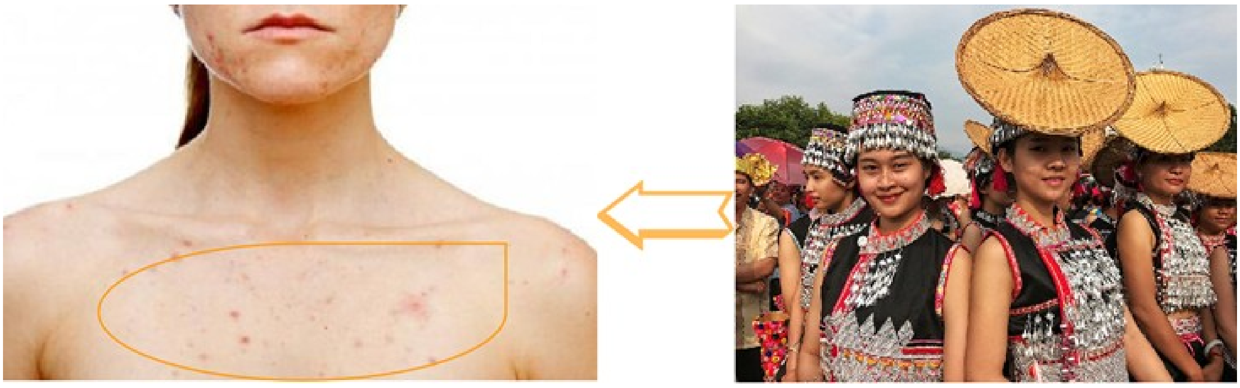


Figure 1. Dai clothing bacterial property

The so-called functional antimicrobial textiles are new textile materials that can effectively inhibit or kill microorganisms, such as bacteria and fungi, and have healthcare functions. They can effectively prevent the spread and infection of diseases and greatly reduce the risk of cross-infection in public environments [1,2]. At present, functional antimicrobial textiles are mainly divided into protective antimicrobial textiles and daily antimicrobial textiles according to their applications; they can be divided into two categories according to their preparation methods, namely, antimicrobial textiles prepared from raw fibres with intrinsic antimicrobial activity and antimicrobial textiles that are endowed with antimicrobial properties through post-finishing methods [2]].

Many plants in nature have an inhibitory effect on bacteria, such as hemp, bamboo, and kapok. These plants contain hemp sterols, flavonoids, phenolic substances, anthraquinones, flavonoids, and triterpenoids, which can interact with bacterial cells' cell walls and internal proteins to destroy their functions and inactivate bacteria [8-11]. Therefore, they can be directly used to make antibacterial textiles after simple treatment. This study is based on the kapok plant, which is unique to Yunnan. Kapok fibre, as a natural cellulose fibre, is widely distributed in southern China (such as Yunnan, Guangdong, and Hainan) and abroad (such as Nigeria and India). Its planting conditions are relaxed, it can make full use of barren land, it is green and environmentally friendly, it has the potential to replace other natural fibres, and it has unique functional advantages [1,2].

Professor Wang Fumei and Professor Yu Weidong of Donghua University studied the basic structure, properties, and spinnability of kapok fibres. The chemical composition of kapok fibres mainly includes cellulose, lignin, and a small amount of ash powder, xylan, and wax. Its high, hollow structure and multi-microporous surface make it difficult for bacteria to reproduce, and it has significant antibacterial and anti-mite effects [10].

Research by Feng Jie et al. showed that the antibacterial rate and anti-mite effect of kapok fibre exceeded 90%, and it also had excellent thermal insulation properties, making it suitable for the design and development of textile and clothing fabrics [13]. However, kapok fibre is short and difficult to spin.

Sun Jingxia et al. found through research that the performance of kapok blended yarn is affected by the blending ratio, that a kapok content exceeding 50% will reduce yarn strength, and that compact spinning is more conducive to improving quality [11,13].

Yan Xiaofei et al. investigated the antibacterial properties of Hainan kapok fibre and Indonesian kapok fibre, respectively [12]. Through experiments, they speculated that high-temperature treatment inactivates the flavonoids in the kapok fibre. Therefore, the antibacterial effect of kapok fibre sterilised with alcohol is better than that of kapok fibre sterilised with high temperature and high pressure.

Silver fibre is a high-tech product that uses special technology to permanently bond a layer of pure silver to the fibre surface. This structure allows the silver fibre to maintain its original textile properties and gives it all the long-lasting antibacterial functions of silver. Silver fibre has been tested to resist 99.9% of bacteria exposed to the surface within 1 hour. Most other antibacterial products cannot achieve the same effect after 48 hours of testing. Silver fibre is a tight aggregation of silver and fibre. It is permanent and will not decrease with time and washing. Even after washing 250 times, its antibacterial function is still not reduced. Nanosilver has the advantage of broad-spectrum antibacterial properties, which makes it often used in the antibacterial finishing of textile fabrics [17-19]. At present, many domestic and foreign scholars have studied the preparation process of nanosilver antibacterial fabrics, including chemical methods, physical methods, etc, but there are few studies on the blending of nanosilver fibre and kapok fibre in Dai costumes.

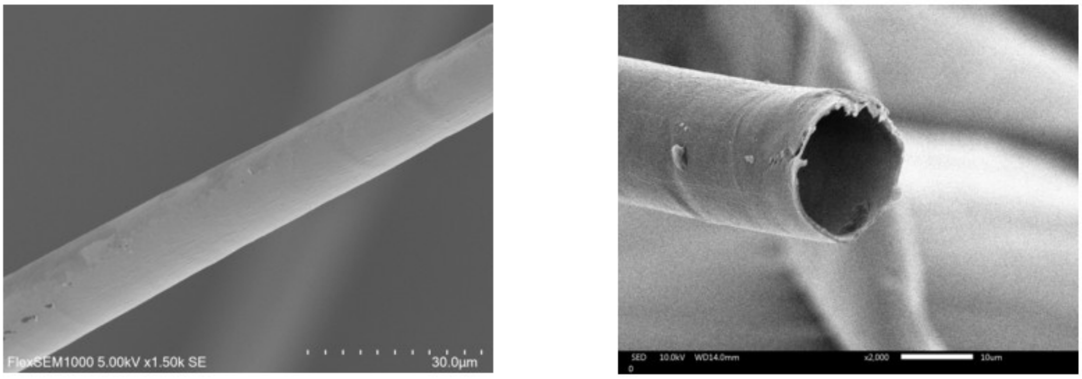
In summary, kapok fibre, with its unique structure and properties, has shown broad application prospects in the fields of textiles, clothing, and industrial textiles. However, Dai's clothing design and creativity are lacking. In addition, its poor elasticity, wrinkle resistance, wear resistance, and itchy feeling make it generally accepted by the market and consumers. This greatly limits the application of natural plant fibres in antibacterial textiles to a certain extent and even affects the development of new varieties. Therefore, this paper explores the blending of kapok fibre with silver fibre and viscose fibre to improve the antibacterial and wearing performance of Dai clothing.

Selection of antibacterial fabrics for Dai clothing

Physical properties of kapok fibre

Kapok fibre is a non-cotton cellulose that grows naturally in tropical and subtropical regions and is produced in tree fruit. Microscopic observation shows that the cross-section of kapok fibre shows a distinct pore structure, with an unusually thin tube wall and an air-filled cavity inside. The hollowness is as high as 80% to 90%, far exceeding the approximately 40% of chemical fibre [20]. Scanning electron microscopy was used to study kapok fibres' vertical and cross-sectional views, as shown in Figures 2 and 3.

Figure 2. Kapok flowers and fruits



a) b)

Figure 3. SEM scanning image of: a) Surface structure of kapok fibre, b) Cross-sectional structure of kapok fibre

The hollow structure of kapok fibre can store a large amount of gas, and the fibre wall is thin, so kapok fibre is light and has excellent thermal insulation and isolation functions. Therefore, kapok fibre is widely used in buoyancy, thermal insulation filling, and sound insulation.

At the same time, Xiao Hong and his research team used a thermogravimeter (TG) and a differential scanning calorimeter (DSC) to explore the thermal properties of kapok fibre and compared them with cotton fibre [14]. The experimental results show that kapok fibre has better heat dissipation and moisturising effects than cotton fibre (Figure 4).

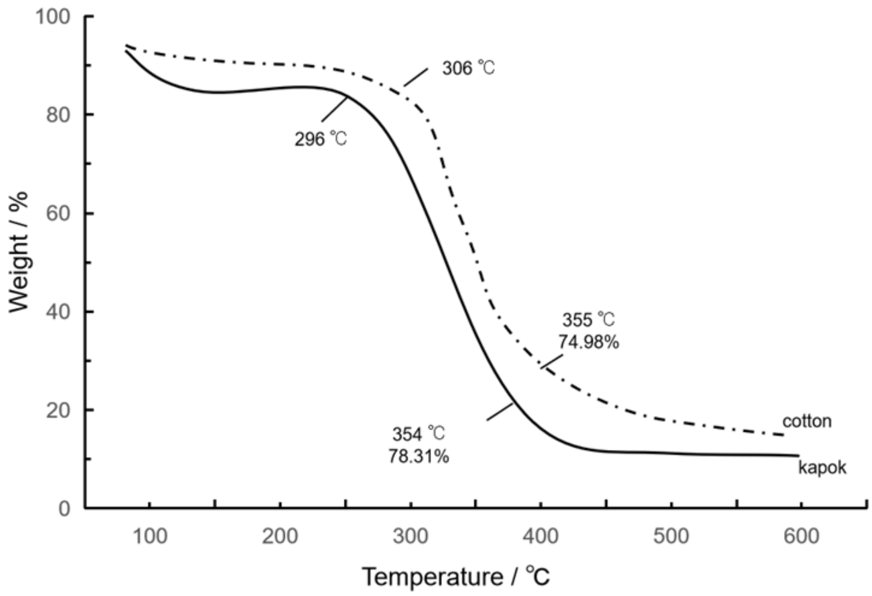


Figure 4. Thermogravimetric spectra of kapok and cotton fibre

Kapok fibre blending

Known studies have found that kapok fibre is most often blended with cotton fibre, improving the warmth retention, wrinkle recovery, and wicking effect of the fabric and giving the fabric UV protection as the blending ratio increases. However, blending will cause the mechanical properties and hydrophilic properties of the yarn to decrease [15]. To avoid a significant impact on the yarn properties and weaving process, the blending ratio of kapok fibre and cotton fibre should not exceed 30% [16].
Kapok fibre can also be blended with synthetic fibres such as polyester and acrylic. When blended with polyester, it can improve the wrinkle resistance, wear resistance, and crispness of the fabric; when blended with acrylic, it can make the fabric fluffy and soft, easy to wash and dry quickly. Kapok fibre blended with viscose fibre can improve the moisture absorption, breathability, and antistatic properties of the fabric, but there is still room for improvement in wrinkle resistance, antibacterial durability, and elasticity. To meet the long-term antibacterial, breathable, and wrinkle-resistance requirements of Dai clothing, kapok/silver fibre/viscose/polyester fabrics are selected for blending according to the purpose.

Yarn blending of antibacterial kapok fibre

First, through the blending process the two blended yarns of

- 18tex kapok (20) + viscose fibre (35) + polyester (35) + 30D silver fibre (10) and
- 18tex cotton (91) + 30D spandex (9)

are processed, and the two blended yarns are woven through:

pretreatment → mixing → cotton opening → cotton combing → drawing (two passes) → coarse yarn → fine yarn → winding.

Then, to increase the elasticity of traditional Dai clothing, we use weft knitting technology to weave the fabric, using traditional plain needle and rib weaving techniques.

Knitting weaving process

Equipment parameters:

Machine: German Meyer OVJA1.6E double-sided jacquard machine

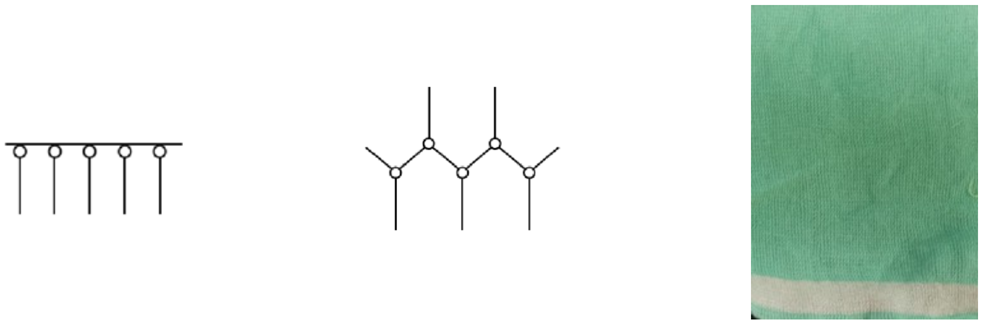
Machine gauge: 18 needles/25.4 mm

Barrel diameter: 762 mm (30")

Road: 48F

Needle count: 1872

The weaving diagram is shown in Figure 5.



a) b) c)

Figure 5. Two knitting organisational structures a) Weft flat needle, b) Ribbed pattern, c) Physical photo

Antibacterial testing of kapok fibre-blended fabrics to determine their antibacterial properties

Experimental Materials

In the experiment, two 20 mm diameter disks of kapok fibre, silver fibre, and cotton synthetic fabric were prepared as samples. Staphylococcus aureus (ATCC6538) and Escherichia coli (ATCC11229) were used as bacterial species. The fabric specifications are shown in Table 1.

Table 1. Fabric specification parameters

Fabric No.	Fabric raw materials	Fabric thickness (mm)	Area density (g m^{-2})	Vertical density Column (5 cm)$^{-1}$	Horizontal density column (5 cm)$^{-1}$	Fabric organisation
1	18tex kapok(20)+Viscose fibre(35)+terylene(35)+30DSilver fibres（10）	0.770	180	124	79	weft needle
2	18tex cotton (91)+30Spandex (9%)	0.694	175	130	88	weft needle

Experimental instruments or equipment

The main equipment used in the experiment is as follows:

Table 2. Main experimental instruments or equipment

Name	Required conditions
Biochemical incubator	Temperature 30 °C
Shaking water bath	Oscillation frequency of 120 beats/min
Refrigerator	Temperature 4 °C
Vertical automatic pressure steam sterilizer	Temperature 121 °C
Ultra clean table	Sterile

<u>The experimental principle</u>

According to the requirements of GB/T20944.1-2007 "Evaluation of Antibacterial Properties of Textiles Part 1: Agar Plate Diffusion Method", the antibacterial properties of kapok synthetic fabric samples were tested. First, nutrient-rich broth agar culture medium was injected into the bottom of the culture dish, and then the bacterial liquid was smeared on the agar surface, and then the sample was spread on the agar. After an appropriate culture period, the antibacterial effect of the sample was evaluated, and a qualitative evaluation was performed based on the reproduction of bacteria at the bottom and around.

<u>Preparation before the experiment</u>

Activation of bacterial strains and preparation of test bacteria according to the specific operating steps of GB/T20944.1-2007:

- Take out the desired strains from the frozen strains.
- Pre-culture on appropriate medium to allow rejuvenation and proliferation.
- Prepare the required test bacterial suspension according to the experimental requirements.

The agar medium preparation method was prepared the corresponding agar medium according to the requirements of different strains:

1) Basic components for culturing E. coli:

   1 g Tryptone

   0.5 g yeast powder

   1 g sodium chloride

   2 g agar

Dissolve the above ingredients with high-purity water, heat until completely dissolved, then sterilize and pour into a culture dish, and wait to solidify into an agar culture medium.

2) Composition of Staphylococcus aureus culture medium:

   1 g Tryptone

   0.3 g beef extract powder

   0.5 g sodium chloride

   2 g agar powder

Dissolve the above ingredients with high-purity water, heat until completely dissolved, then sterilise and pour into a culture dish, and wait to solidify into an agar culture medium.

3) Increase the volume of basal culture medium to 100 ml to ensure uniformity and quality of the culture medium.

Experimental procedures

1) Disinfection preparation

Two transparent glass culture dishes and agar culture media of Escherichia coli and Staphylococcus aureus were placed in a vertical automatic high-pressure steam steriliser. Use 121 ^{o}C high-pressure steam to treat for 15 minutes. After the treatment is completed, wait on a sterile, clean bench for 2 hours and 45 minutes to ensure complete disinfection.

2) Ultraviolet sterilisation

The sterilised samples were placed on a clean bench and irradiated with ultraviolet light for 30 minutes for sterilisation.

3) Sample preparation

Using a sterile pipette, 100 μl of the test bacterial suspension of Escherichia coli and Staphylococcus aureus were taken and spotted on two agar media respectively. After oscillating and mixing, use sterile tweezers to gently spread the sterilised sample so that it is tightly combined with the agar medium.

4) Constant temperature culture

Place the glass culture dish in a 30° C constant temperature incubator and culture for 24 hours. During the culture process, ensure that the sample is always in contact with the agar medium and does not move.

5) Observation

After culturing for 24 hours, the glass plates were taken out to observe the colony growth of Escherichia coli and Staphylococcus aureus on the agar medium.

6) Results analysis

Observe whether a ring-shaped area without bacterial growth is formed around the test sample, that is, whether an inhibition zone has formed. Note that the experiment must be conducted in a sterile environment throughout, and the experimental design must be strictly followed to obtain accurate results.

$$S_{\text{Antimicrobial ring}} = \pi \left(R^2 - r^2\right) \tag{1}$$

Where S represents the area (mm ^{2}), R is the radius of the outer ring of the antibacterial ring (mm), and r is the sample radius (mm).

Table 3. Evaluation of antibacterial detection effect on *Staphylococcus aureus*

Fabric number	Antibacterial ring area	Is there bacterial growth under the fabric sample	Antibacterial effect
1	≥ 0	A large number	nothing
2	2.0mm	nothing	good

Table 4. Evaluation of antibacterial detection effect on *Escherichia coli*

Fabric number	Antibacterial ring area	Is there bacterial growth under the fabric sample	Antibacterial effect
1	≥ 0	A large number	nothing
2	2.9mm	nothing	good

Experimental Results

After culturing at 30 °C for 24 hours, the growth of the colonies can be seen in Figures 6 and 7. The results show that in the antibacterial experiments of Staphylococcus aureus and Escherichia coli, no bacteria grew at the bottom of the samples (d) and (c) of fabric number 2, and an antibacterial ring was formed around them, with no colonies inside. According to the evaluation criteria in Table 4, the test shows that the kapok synthetic fabric samples exhibit effective antibacterial effects and can inhibit bacterial growth and reproduction. In Figures 6 and 7, (a) and (b) of fabric number 1 did not produce an antibacterial ring. (d) and (c) produced an antibacterial ring of 2.0 mm and 2.9 mm, respectively. By comparing the antibacterial experiments, it can be found that the kapok-blended silver fibre fabric has a very obvious antibacterial function compared with the ordinary cotton fibre fabric. The antibacterial function of kapok fibre is related to its special hollow structure. The hollow structure of kapok fibre can instantly absorb and evaporate the water inside it, making it difficult to hydrolyse, reducing the possibility of microorganisms surviving, and thus obtaining natural antibacterial function. The antibacterial function of silver fibre is that silver ions can absorb microorganisms in liquid, making the enzymes that microorganisms rely on to breathe ineffectively, thereby removing microorganisms. Silver ions have strong antibacterial ability, and a few billionths of a milligram of silver can purify 1 kilogram of water. Wearing this kind of fabric with perspiration function can partially inhibit bacterial reproduction and is beneficial to health.

Figure 6. Antibacterial test for *S. aureus*

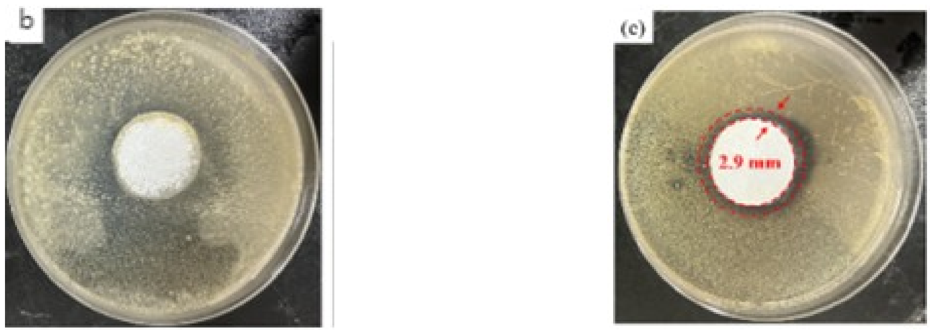


Figure 7. Antibacterial test for *E.coli*

INNOVATION OF THE COLOUR EXTRACTION METHOD OF THE DAI COSTUME

Design method of colour extraction

Based on the existing Dai antibacterial fabrics, according to the epic records and the current fashion trends, the following colour combinations are extracted as the main colour combinations of clothing. The traditional clothing of the Dai people makes full use of colour matching and is also a "colour symbol" for conveying information to the outside world. Coordinated colour matching occupies the main part of the Dai style, which is unique and bright, occupies a large area, and has a strong visual impact.

Table 5. Colour characteristics of traditional Dai costumes

Implication	Trait	Colour	Graphical representation
Indicates the population lineage	Dai Ya: Black main colour keynote, waist, skirt embroidered with five-colour lace, black rectangular cloth leggings	Black, five-colour lace, etc	
	Dai wine: green main colour tone, multi-colour satin splicing	Red, green, purple, yellow, white, black, etc	
	Dehong area: Black dress, multi-colour splicing	Blue, white, etc	
Stand for social status	Nobility: "Meng" class tube skirt can weave more than three golden rings, embroidered gold dragon phoenix; "Weng" class tube skirt can weave one to two silver rings, embroidered silver star pattern	Gold, silver, black, purple, red, etc	
	Ordinary: can weave a colour circle	Black, red, green, purple, etc	

According to the colour trends in 2025 and the Dai people's preference for colours, the following two colours are selected as the main colours of the design and combined with white for creative design.

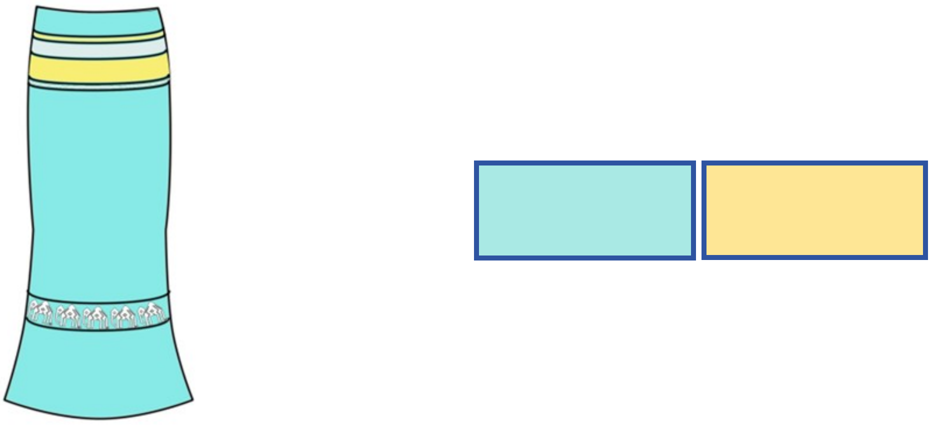
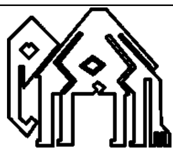
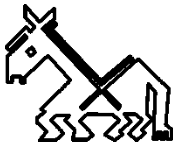
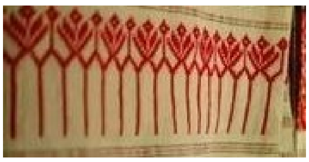


Figure 8. Selection of the above two colour designs

Innovation of pattern extraction methods

The patterns popular among the Dai people are extremely beautiful, with strong life colours and ethnic characteristics. They are composed of rare animals, plants and flowers, geometric figures, etc., which are abstract and generalised but still flexible and lifelike. Each pattern has a special meaning. According to the data documents and image records, they can be roughly divided into three types: animal patterns, plant patterns, and geometric patterns (Table 6).

Table 6. Abstract summary of the patterns of traditional Dai skirt clothing

Name	Original image	Graphics
Elephant pattern		
Peacock pattern		
Horse pattern		
Geometric pattern		
Plant pattern		

Extraction and semantic extension of pattern symbols. The symbols of peacock, elephant, plant, etc., in the traditional Dai patterns all have profound cultural semantics (Table 7).

Table 7. The transformation of traditional and modern values of Dai pattern symbols

Pattern symbol	Traditional symbolic meaning	Semantic extension and application in modern design	Cultural value communication
Peacock	Auspicious, Lucky, and Happy	As a symbol of happiness and auspiciousness, peacocks can embody their nobility and elegance through their gorgeous colours and intricate feather details. Adopting a symmetrical layout or colourful gradient in clothing enhances visual aesthetics and cultural recognition.	Convey the pursuit of a better life in Dai culture and provide positive psychological suggestions to the wearer, enhancing cultural identity.
Elephant	Religious beliefs, spiritual protection, strength, and protection	Symbolizing the piety and protective power of religious beliefs, the design uses simple geometric elephant trunk and ear symbols for abstract expression, forming patterns with a sense of power, suitable for cuffs, hemlines, and other parts.	Strengthening the cultural connotation of faith protection, enabling wearers to feel peace and strength, and realizing the inheritance of cultural spirit.
Plant	Vitality, Nature Worship, and Reverence	The plant pattern symbolizes the affinity between vitality and nature. Symbols such as vines and leaves are selected in the design, and flowing lines are used to express the dynamic growth of life. It is suitable for use in areas such as collars and skirts to add vitality to clothing.	Expressing the Dai people's admiration for nature, conveying the concept of ecological harmony, and meeting the aesthetic demands of modern people for closeness to nature.

Innovation in Dai clothing design

Elephant patterns symbolise a good harvest, a good life, etc. Therefore, as shown in Figure 9, the pattern selection of the " Dai Weaving " clothing combines the elephant and plant patterns that symbolise the good meaning of the Dai people. The colour integrates modern aesthetic standards, and the colour combination of aqua blue and bright yellow is selected in combination with the colour trend of 25 years. Due to the hot climate, a one-shoulder design was selected. Wearing it in modern life reflects national customs and subtly produces positive psychological implications for the wearer.

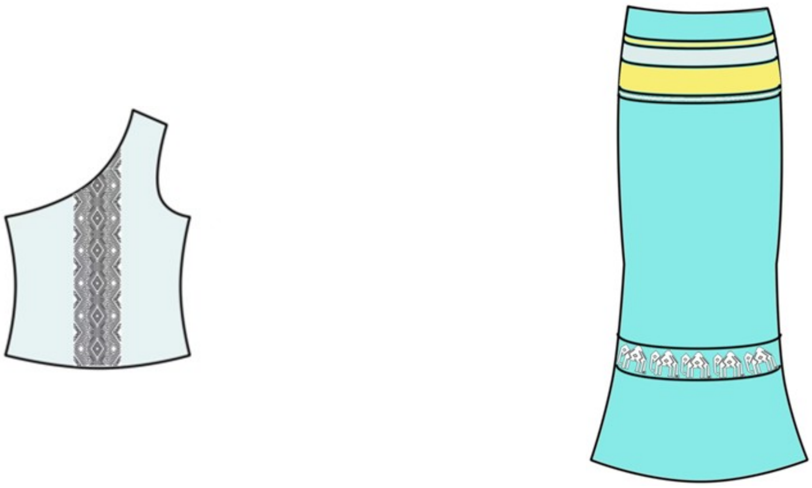


Figure 9. Fabric pattern feature design

"Dai Weaving" knitted garments display. Through this design case, the essence of antibacterial kapok synthetic fibre and Dai embroidery patterns are successfully combined with modern knitted garment design to create fashionable clothing that is full of traditional ethnic cultural charm and modern aesthetic value.

Figure 10. Display of finished antibacterial knitted garments from Dai weaving

CONCLUSION

The new Dai antibacterial fabric, blended with kapok fibre and silver fibre, has significant antibacterial properties, with inhibition zones of 2.0 mm and 2.9 mm for *Escherichia coli* and *Staphylococcus aureus*, which is attributed to its lignin component. It changes the problems of poor elasticity, poor wrinkle resistance, and wear resistance, and the itchy feeling of the original fabric. The colours and patterns of Dai costumes are innovatively integrated into fabric design, providing scientific support for Dai costume design while exploring new paths for integrating traditional costumes and modern technology to meet the market demand for healthy and environmentally friendly textiles.

Future research can further explore the influence of the kapok fibre blending ratio and spinning process on textile performance, as well as the application of Dai embroidery patterns in different clothing, to develop textiles with cultural characteristics and health functions.

Author Contributions

Conceptualization - Qi X, Apiwathnasorn C; Data curation - Qi X; Formal analysis - Apiwathnasorn C; Investigation - Apiwathnasorn C; Methodology - Apiwathnasorn C; Project administration - Apiwathnasorn C; Resources - Apiwathnasorn C; Software - Qi X; Supervision - Apiwathnasorn C; Validation - Apiwathnasorn C; Visualization - Qi X; Writing: original draft: Qi X; Writing: review and editing - Apiwathnasorn C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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