Zero-Waste Plant Dyeing: A Feasibility Study on Utilizing Agricultural Waste for Sustainable Textile Production in the Lingnan Region

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Abstract. This research delves into the zero-waste plant dyeing concept, emphasizing the utilization of agricultural waste for dyeing materials to curtail expenses and foster a sustainable natural cycle. The study's objective is to innovate product designs using plant dyes and agricultural waste in a zero-waste dyeing framework. The Lingnan region, renowned for its traditional textile dyeing methods, serves as a case study to assess the dyeing method's efficacy through experiments. The agricultural waste materials encompass crop residues, fruit peels, shells, and more, which are used alongside traditional plant dyes for dyeing various textiles. The textiles are then evaluated on color fastness, intensity, and other dyeing attributes. The findings indicate that agricultural waste dyes are not only sufficient but also yield results that are on par with or surpass those of traditional plant dyes. The adoption of zero-waste plant dyeing not only reduces costs but also supports a circular economy through a closed-loop system. The research concludes that zero-waste plant dyeing is viable in the Lingnan area for creating sustainable product designs, minimizing waste, and reducing costs. The dyeing experiment offers significant insights into the efficiency and effectiveness of agricultural waste as dyeing materials, underscoring the sustainability of this approach for textile production.

1 Introduction

Botanical dyeing refers to dyeing textiles using natural dyes from plants (Wu, 2016). It is a traditional Chinese dyeing and production technique where the dyes used are from the original herbaceous plants (Fu, 2023). Plant dyeing techniques had faded from view amidst the onslaught of industrialisation. However, in recent years, under sustainable design and innovative development of traditional culture, plant dyeing in the Lingnan region has returned to the scene. It is becoming increasingly popular with consumers (Documentary film 'The Age of Record', 2023).

However, with population growth and urbanisation, environmental issues such as over-consumption and the increasing scarcity of natural resources are becoming increasingly evident (Li, 2002). The production of natural dyes by direct farming currently results in substantially high specific costs per kilogram per plant material and per kilogram of dyed material[1]. New strategies are required to establish technically and commercially competitive processes (Thomas, 2006). To solve this problem, Professor Luo Ying (2020) from the School of Fine Arts and Design, Shenzhen University and researcher Wang Qiong (2020) from Nanjing Institute of Botany jointly proposed the concept of 'zero-waste plant dyeing' , practising a sustainable natural recycling model by using agricultural waste as recyclable textile dyes. The idea aligns with a promising concept proposed by Thomas (2006) to produce natural dyes at a lower specific cost by using different plant parts sources to extract natural dyes[2]. The dyeing materials used in traditional plant-dyed textile products are usually flowers, leaves, branches and fruits of plants (refer Fig: 1), some of which have a particular medicinal value and are used for herbal medicine, which is one of the reasons for the high cost of plant-dyed textiles[3].

Fig. 1. Some examples of traditional plant dyed materials (Source: Sun, 2022)

Nevertheless, plenty of crop waste, discarded peels and shells can be used for plant dyeing (refer Fig: 2). Zero-waste plant dyeing offers a promising solution by using agricultural waste as a source of dyes[4]. This approach reduces reliance on non-renewable resources and minimises waste generation by reusing agricultural by-products that would otherwise be discarded. By adopting a zero-waste plant dyeing practice, the printing and dyeing of textile products can move towards a more

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sustainable and environmentally friendly model, in line with the principles of the circular economy. This approach reduces the environmental impact and offers cost-saving opportunities, making it an attractive option for sustainable textile production.

Fig. 2. Some examples of zero-waste plant dyed materials (Source: Sun, 2022)

Therefore, the concept of 'zero-waste plant dyeing' and the development of plant resources and cultural heritage in the Lingnan region are vital issues that should be considered when studying the design of plant-dyed products in the Lingnan region. This study explores the concept of zero-waste plant dyeing and its potential to create sustainable textile products. The specific objectives are to:

1. To explore the feasibility of zero-waste plant dyeing in the Lingnan region
2. To evaluate the effectiveness of zero-waste plant dyeing experiments.
3. To compare textiles dyed with plant-based dyes derived from agricultural waste with those dyed with conventional dyes.

Based on the above information, the conceptual framework of this study is shown in the diagram (refer Fig: 3).

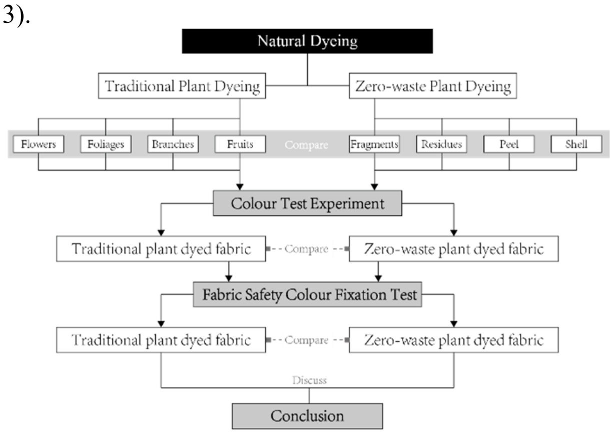

Fig. 3. Framework of Study
(Source: Self-drawn by author, 2024)

2 Plant dyeing in the Lingnan region

The Lingnan region is no exception. People in the Lingnan region used plants such as Mulan, mulberry, betel nut and violet to extract dyes for dyeing (Zhang, 2012). In the Xinxiu Bencao of the Tang Dynasty and the Bencao Tujing of the Song Dynasty, it was recorded that "wood blue came from Lingnan" and was widely used for blue dyeing. The mulberry tree provides a yellow dye, the outer bark of the betel nut provides a teal to dark brown dye, and the flowers and bark of the violet vetch provide a purple and brown dye (Guangdong Folk Craft, 2022).

2.1. The history and current state of botanical dyeing in the Lingnan region

The history of plant dyeing in the Lingnan region is long, dating back to the Tang Dynasty. During the Song Dynasty, the plant dyeing industry in Lingnan began to flourish, producing varieties of plant dyes with local characteristics. During the Ming dynasty, plant dyeing techniques in Lingnan were developed, and the selection, preparation and use of plant dyes were further improved. During the Qing Dynasty, the plant dyeing industry in Lingnan reached its heyday, and many high-quality plant-dyed products appeared (Wang, 2020).

The history of plant dyeing in the Lingnan region is rich and diverse and closely related to the local culture and art. The inheritance and innovation of plant dyeing techniques have become essential to textile craftsmanship and folk art in the Lingnan region. Plant dyeing still has an important place and traditional significance in the Lingnan region (Luo, 2022). Local artisans and artists still use plant dyes for textile dyeing and artistic creation, passing on and promoting the plant-dyeing culture of the Lingnan region.

2.2 Problems and challenges of plant dyeing in the Lingnan region

The Lingnan region in southern China is known for its rich textile heritage and cultural traditions (Xu, 1999). It has been home to a concentration of skilled artisans who have honed their expertise in traditional dyeing techniques for generations. With the concern for sustainable development and the gradual increase in environmental awareness, the plant dyeing industry in the Lingnan region is facing new problems and challenges. The availability of raw materials for plant dyeing has gradually become more complex. The destruction and reduction of natural vegetation in many Lingnan areas (Li et al., 2003) have led to diminishing availability of raw materials. There are also problems with environmental damage and improper harvesting of certain plants, which can hurt the region's plant-dyeing industry. Secondly, the high cost of expenses is also one reason limiting the development of plant dyeing (Wang, 2020). If these problems are not solved, they will significantly affect the development of the botanical dyeing industry in the Lpeopleingnan region. Considering the importance of botanical dyeing in the Lingnan region, people must address these issues to ensure that sustain botanical dyeing and achieve sustainable development while better preserving and protecting the culture[5].

2.3 Excavation and selection of botanical resources in the Lingnan region

Plant dyeing is an environmentally dependent local craft, and the Lingnan plant dyeing process cannot be separated from local plant species (Wu, 2016). When tapping into the plant resources of the Lingnan region, it is crucial to achieve efficient use and comprehensive development of the resources (Rong, 2021).

Table 1. Some dye plants common in the Lingnan region of China.

Herbarium Voucher # (Scientific nam)	Traditional used parts	Zero waste used part	Dye Uses	Color produced
Mo Lan, A01 (Artemisia spp.)	Flower Leaves	Stem	Food Cloth	Yellow orange (flower) Chartreuse (leaves) Light brown (stem)
Mo Lan, B01 (Areca catechu)	Fruit	Fruit peel Leaves	Food Cloth	Brown(fruit) Brown(Fruit peel) Green(leaves)
Mo Lan, H01 (Adenanthera pavonina)	Seed	Bean skin	Food Cloth	Red(Seed) Red(Bean skin)
Mo Lan, L01 (Nelumbo spp.)	Flower	Lotus seed shells Lotus shells Leaves	Food Cloth	Pink(flower) Brown(Lotus seed shells) Yellow (lotus shells) Yellow (leaves)
Mo Lan, M01 (Indigofera tinctoria)	Leaves	Stem	Cloth	Indigo(leaves) Light blue purple(stem)
Mo Lan, R01 (Caesalpinia sappan)	Bark	Xylem	Cloth	Reddish Brown(bark) Light red(xylem)
Mo Lan, S01 (Morus spp.)	Fruit Bark	Leaves	Food Cloth	Purple(fruit) Brown(bark) Yellow(leaves)
Mo Lan, T01 (Santalum spp.)	/	Xylem	Cloth	Reddish brown(xylem)

Note: /'means 'none'

First, select the excellent plant species, and related development programmes should be developed according to the ecological habits of the plants and the guiding ideology of sustainable development(refer Table:1). For example, Hainan dye wood (Hong, 2003) and Guangdong sandalwood (Deng, 2020) are precious dye plants that have achieved harmonious production development and the ecological environment through integrated population management in ecologically conserved farming systems.

Secondly, excavating and using characteristic raw materials can preserve and promote the traditional Lingnan plant dyeing culture and ecological agriculture and the concept of 'zero-waste plant dyeing' to achieve leapfrog sustainable development of the industry. For example, waste plant materials such as mango leaves and yellow mulberry leaves are turned into treasures and made into practical, beautiful and environmentally friendly household items, significantly promoting the development of the local industry (Wang, 2020).

3 Materials and Methods

This study uses an experimental approach to evaluate the effect of zero-waste plant dyeing in the Lingnan region. The prepared zero-waste and traditional plant dyeing dyes to set up and practically explore the dyeing effect on selected commercially available natural textile fabrics using the same dyeing and mordant colouring method. The experiment has two phases, the first phase being the dyeing test and the second phase being the safe fixation of the colour.

3.1. Colour test experiment

Table 2. Traditional Plant Dyeing Group Colour Test Experiment.

No.	Fiber Type	Source	Expect Color
TC1	C	A01-fl	Yellow orange
TC2	C	A01-le	Chartreuse
TC3	C	H01-se	Red
TC4	C	L01-fl	Pink
TC5	C	S01-fr	Purple
TC6	C	S01-ba	Brown
TF1	F	A01-fl	Yellow orange
TF2	F	A01-le	Chartreuse
TF3	F	H01-se	Red
TF4	F	L01-fl	Pink
TF5	F	S01-fr	Purple
TF6	F	S01-ba	Brown
TS1	S	A01-fl	Yellow orange
TS2	S	A01-le	Chartreuse
TS3	S	H01-se	Red
TS4	S	L01-fl	Pink
TS5	S	S01-fr	Purple
TS6	S	S01-ba	Brown

Note: The concentration and pH value of the dye itself are uncontrollable variables, and the rest of the conditions should be set as consistent as possible.

Experimental design

Considering the number of samples, set two primary variables for this experiment: fibre type and dye source. The samples were 36, and the fabric was 10 x 10 cm.Select Artemisia spp. (A01), Adenanthera pavonina (H01), Nelumbo spp. (L01) and Morus spp. (S01). Use Three textile fibres, cotton (C), hemp (F) and silk (S). In the traditional dyeing groups: TC group 1-6, TF group 1-6, TS group 1-6, and zero waste dyeing groups: ZC group 1-6, ZF1 -6, ZS group 1-6. ZC group 1-6, ZF1 group 1-6, ZS group 1-6 (refer Table: 2 & Table: 3) .

During the experiments, the dyeing time, temperature, dose control, pre-treatment and post-treatment were as consistent and stable as possible, except for the concentration of the dyestuff itself and the pH value, which were uncontrollable variables, in order to ensure control of the experimental results. The primary method used in this experiment was: the controlled variable method, and a control group of conventional and zero waste plant dyeing groups was set up for comparative analysis.

Table 3. Zero-waste Plant Dyeing Group Colour Test Experiment.

No.	Fiber Type	Source	Expect Color
ZC1	C	A01-st	Light brown
ZC2	C	H01-bs	Red
ZC3	C	L01-lss	Brown
ZC4	C	L01-ls	Yellow
ZC5	C	L01-le	Yellow
ZC6	C	S01-le	Yellow
ZF1	F	A01-st	Light brown
ZF2	F	H01-bs	Red
ZF3	F	L01-lss	Brown
ZF4	F	L01-ls	Yellow
ZF5	F	L01-le	Yellow
ZF6	F	S01-le	Yellow
ZS1	S	A01-st	Light brown
ZS2	S	H01-bs	Red
ZS3	S	L01-lss	Brown
ZS4	S	L01-ls	Yellow
ZS5	S	L01-le	Yellow
ZS6	S	S01-le	Yellow

Note: The concentration and pH value of the dye itself are uncontrollable variables, and the rest of the conditions should be set as consistent as possible.

Experimental procedure

In the pre-experimental phase, the fabrics coded C, F and S were first de-stained and dried to allow the dye pigment cells to enter the fabric tissue better afterwards to assess the dyeing performance and compare the results. The dyestuffs coded A01 were then classified, with the parts coded A01-fl and A01-le being group T dyestuffs and the part coded A01-st being group Z dyestuffs; the dyestuffs coded H01 were classified, with the part coded H01-se being group T dyestuffs and the part coded H01-bs being group Z dyestuffs; the dyestuffs coded L01 were classified, with the part coded L01-fl being group T dyestuffs and the parts coded L01-lss and L01-st being group Z dyestuffs. The dyestuffs coded L01 are classified, with the parts coded L01-lss, L01-ls and L01-le being group Z dyestuffs; the dyestuffs coded S01 are classified, with the parts coded S01-fr and S01-ba being group T dyestuffs and the part coded S01-le being group Z dyestuffs. The plant dyes are usually dried and de-watered plants, which need to be soaked and softened in order to be able to cook the sap out of the plant so that the cellular tissue is loosened and the colour fixation effectively.

During the formal experimental phase, three sets of pots of approximately the same size and capacity (1L capacity) are prepared, the dyestuff and dyeing aid is placed in the pots, water over 90° C is poured in, stirred and dissolved, after the dyestuff has been evenly dissolved, the dried fabric is submerged in the dyeing solution, the amount of water should be at least 1.5 times the weight of the fabric, stirred for 10 minutes according to the classification, after which the colouring is left to stand for 120 minutes according to the grouping. After soaking, the semi-finished products are gently washed to remove the floating colours and left to dry in a sunless place.

Experimental results

After the first stage of the dyeing process, according to the observation and colour card comparison, both groups T and Z are plant-dyed dyes, the colour of the coloured fabric is light and elegant, and the smell is fresh, which is incomparable to the synthetic chemical dyes. Eighteen samples' colours from group T followed the expected colour, with moderate colour brilliance and brightness. Eighteen samples' colours from group Z followed the expected colour, and the overall colour was slightly higher in brightness compared to group T, with light yellowish brown colour. The colour tone, brightness and purity of ZC2, ZF2, ZS2 and TC3, TF3 and TS3 were the same, and the results were satisfactory.

3.2. Fabric safety colour fixation test experiment

Experimental design

Three variables were set based on the first stage of colour testing experimental samples: mordant, fixing time and number of washes. The number of experimental samples was 432, and the fabric size was 10 x 10 cm, set up groups with different mordants: MS group 001-144, MV group 001-144 and MA group 001-144. The study observed and recorded the characteristics of each mordant in combination with the fabric to select the mordants with good colouring effect and safe from fading.

Experimental procedure

Three common mordants were chosen in the pre-experimental phase: safe, natural salt, white vinegar and Ash water[Plant ash water, that is, ash obtained from burned waste plant stalks, wood or other plant parts, is mixed with clear water or rainwater in a certain proportion and filtered to obtain an organic mordant（Ma, 2018）.]. The results of the acid and alkaline pH tests were as follows: the pH value of the S mordant was around 7, which was neutral. The mordant V has a weakly acidic pH value of around 5.3-6, and the mordant A has a weak alkaline pH value of around 7.5-8. Both the water fastness and the pH value are safe for use in everyday life. As the number of samples for the colour test was insufficient for this colour fixation test, 12 more replicates were made in the same way as in stage 1. As this experiment was to verify the effect obtained by combining different mordants with the fabric, the cooking was divided into three experiments, with the mordants S, V and A for each of the three experiments.

In the formal experiment, the colour semi-finished products were divided into three groups according to the different mordants for fixing, using hot water at 60 degrees C. The fixing agent was dissolved and put into the fabric, stirred and kept in the same amount of water as the dyeing stage. Each group was kept warm for 90 minutes and 180 minutes, respectively, and rinsed with clean water at the end of the experiment to make the colours more accurate. Depending on the mordant, groups were grouped during drying to avoid confusion of samples due to lack of grouping.

Experimental results

The relationship between colour fixation time, number of washes and colour of salt on cotton, linen and silk fabrics; the relationship between colour fixation time, number of washes and colour of white vinegar on cotton, linen and silk fabrics; and the relationship between colour fixation time, number of washes and colour of ash water on cotton, linen, silk and fabrics.

According to the results of the MS group control experiment, the colour fixation effect of the mordant coded S was as follows: at a dyeing time of 90mins, without washing, all samples showed a deepening of the colour, but the colouring was weak. At a dyeing time of 180mins, without washing, the colour of all samples was significantly darker and more intense than the 90mins unwashed samples. At 180mins and one wash, all samples showed no significant fading. At 180mins and two washes, the colour of all samples did not change significantly, except for MS004, MS012, MS016, MS020, MS024, MS076, MS084 and MS088, which had faded.

According to the results of the MV group control experiment, the colour fixation effect of the mordant coded V was as follows: at a dyeing time of 90mins and without washing, samples MV001, MV005.... ...MV141 were darkened, with samples MV001, MV009, MV017, MV021, MV077, MV085 and MV101 showing uneven dyeing. Samples MV050 to MV072 and MV121 to MV144 were slightly darker than the other samples, with the most incredible intensity of longitudinal staining. At a dyeing time of 180mins, without washing, all samples of equal condition were darker than the 90mins unwashed samples, except for samples MV026, MV030, MV034, MV038, MV042, MV046, MV097, MV101, MV105, MV109, MV113 and MV117, where there was no change in colour. The samples were darker than the 90mins unwashed samples. At a staining time of 180mins and one wash, only samples MV027, MV031, MV035, MV039, MV043, MV047, MV099, MV103, MV107, MV111, MV115, and MV119 showed a slight fading of colour, while the rest of the samples in the same condition showed no significant change in colour. The colour of all samples did not fade significantly at a staining time of 180mins and two washes.

According to the MA group control experiment results, the colour fixation effect of the mordant code A was as follows: at a dyeing time of 90mins and without washing, samples MA001, MV005.....MA021, MA073, MA077... MA093 samples had an intense colouring and a yellowish-green tone compared to the other groups. The remaining samples under the same conditions were slightly darker but less intensely coloured. At 180mins of dyeing time and without washing, samples MA002, MA006, MA010, MA014, MA018, MA022, MA074, MA078, MA082 and MA094 were darker, with an overall brownish tint and more vital colouring than the other groups. The remaining samples in similar conditions were significantly darker than the 90mins unwashed samples, with a much stronger colouring. At 180mins and one wash, no discolouration was evident in any of the samples. At 180mins and two washes, there was no significant change in colour in any of the samples.

4 Results and Discussion

The abundance of plant dyes in the Lingnan region provides ample resources for experimentation, and traditional plant dyes are rich in elegant colours. The zero waste plant dyes are mainly yellow, green and light brown tones with fresh colours and a narrower colour gamut than the traditional plant dyes due to their source mainly being extracted from agricultural waste. A comparison of the dyeing performance of the two groups from the dyeing test experiment in June 2023 showed that the efficiency and effectiveness of the dyeing process using traditional plant dyes and zero waste plant dyes were generally the same based on the results of the dyeing experiment. Both the traditional plant dye group and the zero-waste plant dye group achieved the desired dyeing results, with the finished product having a fresh plant fragrance, uniform colour and good dyeing performance (refer Fig: 4). The colour fastness of the three mordants, including the length of fixation and washing tests, was evaluated from the safe fixation tests on the dyed samples from the dye test experiments to determine the colour stability and durability of the traditional plant dyed textiles and the zero-waste plant-dyed textiles, which were highly applicable, with no significant changes or fading in the majority of the samples after two washes. Moreover, in a small percentage of samples, the fading was due to the fibre type, not the dye. Both groups of dyes have specific stability and meet the requirements of the textile products.

Fig. 4. Samples of TC group & ZC group
(Source: Self-drawn by author, 2024)

Based on these results and analysis, the feasibility of implementing zero-waste plant dyeing in the Lingnan region is present. The advantages and challenges of using agricultural waste as a dye source are considered, as well as the potential for cost savings and a closed-loop system. The experimental results provide insights into the efficiency and effectiveness of agricultural waste in plant dyeing and contribute to the broader discussion on sustainable textile production.

4.1. Significance and applications

Zero-waste plant dyeing has several implications and applications of importance. Firstly, using agricultural waste as a source of dyestuff, zero-waste plant dyeing can achieve significant cost savings for textile manufacturers and reduce the production costs associated with dyeing, thus achieving cost savings in textile production. This cost-saving aspect makes zero-waste plant dyeing an attractive option for sustainable textile production. Secondly, zero-waste plant dyeing offers the possibility of creating new and innovative sustainable product designs. By using plant-based dyes derived from agricultural waste, diverse colours and textures can be produced, creating unique and environmentally friendly textiles. By incorporating these sustainable materials into product design, textile manufacturers can meet the growing consumer demand for eco-friendly and socially responsible products. In addition, zero-waste plant dyeing implements the concept of a closed-loop system in line with the principles of a circular economy. Agricultural waste as a dye source, a circular system can be created that reduces waste generation and promotes resource efficiency. This practice integrates waste into the dyeing process, creating a circular flow that turns waste into a valuable resource, minimising environmental impact and contributing to a more sustainable textile industry. Finally, the practice of zero-waste plant dyeing aligns with the core principles of the circular economy, emphasising waste reduction, resource efficiency and sustainability. This approach contributes to the overall goal of a more environmentally responsible and socially conscious textile industry. By adopting zero-waste plant dyeing practices, stakeholders in the textile industry can work together to create a circular and sustainable production system.

4.2. Limitaions

Despite its contributions and potential implications, this study has several limitations. Firstly, the research focused solely on the Lingnan region, limiting the generalizability of findings to areas with different agricultural waste materials and dyeing practices. Further research is needed to assess the applicability of zero-waste plant dyeing in diverse contexts. Secondly, the research focused primarily on the dyeing properties of the textiles rather than the overall environmental impact. Future studies should provide a more comprehensive assessment of the sustainability of zero-waste plant dyeing.Moreover, the long-term durability and performance of zero-waste plant-dyed textiles were not extensively assessed, warranting further investigations. Lastly, the study did not consider potential variabilities in agricultural waste materials due to agricultural practices and seasonal factors, such as composition and quality variations. Future research should address such variability for a comprehensive understanding. These limitations require future research to provide a multidimensional analysis of zero-waste plant dyeing, accounting for different regions, environmental impacts, socio-economic aspects, and agricultural waste material variations.

5 Conclusion

In conclusion, this study explored the concept of zero-waste plant dyeing in the Lingnan region, focusing on using agricultural wastes. Through dyeing experiments and evaluation, this study demonstrated the effectiveness of plant-based dyes derived from agricultural waste, showing comparable or better results than traditional dyes regarding colour fastness, strength and other dyeing properties. The findings suggest that zero-waste plant dyeing can be successfully implemented in the Lingnan region to create sustainable product designs while minimising waste and reducing costs. There are many benefits to implementing zero-waste plant dyeing practices, including cost savings, creating sustainable product designs, creating a closed-loop system, and aligning with circular economy principles. Agricultural waste as a dye source, the textile industry can reduce its environmental impact, promote resource efficiency and meet the growing demand for sustainable products. Further research could explore other aspects of zero-waste plant dyeing, such as scalability, long-term viability and the potential for large-scale adoption. The textile industry can move towards a more sustainable and environmentally friendly future by continuing to develop and refine sustainable dyeing technologies.

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