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Article

Application of nano-biocolorants in Yao nationality patterns

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Abstract: Nanobiodyeing refers to an innovative process of dyeing by extracting pigments from various pigment-containing organisms in nature and processing them with nanotechnology. No or very few chemical additives are used in the dyeing process. The excellent color culture of natural biological dyeing should be given new meaning so as not to cause a break in traditional skills. Natural biological dyes are non-toxic and harmless, non-allergenic and non-carcinogenic to the skin. They have good biodegradability and environmental compatibility. Their colors are soft, natural and distinctive. At the molecular level, the application of nano-bio-pigments can involve the molecular structure and interaction of the dyes used in Yao patterns. Through biomolecular design, we can develop nano-pigments with specific colors and stability. These pigments can better integrate with the natural fibers in Yao patterns, providing more vivid and lasting colors.

Keywords: nanotechnology; biological dyeing; natural pigments; Yao patterns; traditional skills

1. Introduction

During the extraction of biological raw materials, it is necessary to comply with local laws and regulations and produce the required materials reasonably under the premise of protecting the environment.

Plant dyes can be used not only in the textile printing and dyeing industry, but also in many other fields such as food, beverages, papermaking, plastics, building materials, handicrafts, daily chemical products, and pharmaceuticals [1]. They can completely replace chemical colors and benefit mankind. Many natural pigments are also used in the development of new functional textiles due to their special composition and structure [2]. In particular, some plant dyes themselves come from medicinal plants, such as madder, indigo, tulip, and safflower, which are dyed into new fabrics with insect-repellent, bactericidal, skin-protecting, and anti-allergic properties [3].

1.1. Classification by color

Plant dyes can be divided into the following categories by color:

1) Purple series: Comfrey, red sandalwood, wild amaranth, and baseleaf.
2) Red series: Madder, safflower, and sappanwood.
3) Yellow series: Gardenia, turmeric, curcuma, ginkgo, and chrysanthemum.
4) Green series: Buckthorn and amaranth.
5) Brown and brown series: Tea, mulberry, bayberry, oak, and catalpa leaves.
6) Blue series: Indigo, woad, various species of indigo.
7) Gray and black series: Water chestnut, gallnut, sumac, koelreuteria, oak leaves, and lacquer sedge.

1.2. Classification by dyeing method

Plant dyes can be divided into the following categories according to dyeing method:

Direct dyes: Turmeric, safflower, pomegranate, etc.

Vat dyes: Indigo, woad, various species of indigo.

Mordant dyes: Madder, lithospermum, hematoxylin, pomegranate peel.

Disperse dyes: Henna, madder, rhubarb.

Acid dyes: Saffron, locust flower, turmeric, pomegranate, etc.; basic dyes: Phellodendron, coptis, etc.

1.3. Classification by chemical composition

Plant dyes can be categorized based on their chemical composition, which influences their interaction with various biological tissues and cellular processes. They include carotenoids, anthraquinones, naphthoquinones, flavonoids, diketones, indoles, and alkaloids [4].

Carotenoid dyes are primarily yellow, orange, and red [5]. These pigments, found in sources such as carrots and crocetin, play a role in protective coloration and antioxidant activity within biological systems [6].

Anthraquinone dyes are yellow-red pigments found in plant roots and animal bodies, including rhubarb, madder, lacquer, and carmine. Their structure, comprising an anthraquinone matrix with hydroxyl or carboxyl groups, contributes to their stability and ability to interact with metallic ions, enhancing their use in fabric treatment for biomechanical applications [7].

Anthraquinone dyes also include predominantly purple variants found in the root of lithospermum. Flavonoid dyes, mainly yellow and red, are sourced from plants like bayberry, reed, scutellaria, and safflower. These compounds can influence cellular processes and provide antioxidative benefits.

Indigo structures in natural dyes, such as indigo and Tyrian purple, are significant for their biochemical interactions. Indigo, present in plants as glycosides, is extracted from Polygonum indigo. The extraction process involves soaking the stems and leaves in water, followed by fermentation, hydrolysis, and oxidation to obtain the dye [8]. The resultant indigo interacts with cellular components and can be used for various biomechanical and bioengineering applications [9]. See the **Table 1** below for the plant sources of the colors:

Table 1. Plant dyes.

Chemical classification of pigments	Plant Name	Dye category	Hue	Dyeing material
	Sophora japonica	Mordant	Yellow	Flower
	Scutellaria baicalensis	Mordant	Yellow	Root
	Bayberry	Mordant	Yellow, Brown	Bark
	Safflower	Direct	Red	Flower
Flavonoids	Wild lacquer	Direct	Yellow	Leaves, Stems
	Marigold	Direct, Mordant	Yellow	Flower
	Rubus chinensis	Direct, Mordant	Purple, Black	Fruitage
	Grape	Mordant	Red	Peel
	Onion	Mordant	Yellow, Red	Peel

Table 1. (*Continued*).

Chemical classification of pigments	Plant Name	Dye category	Hue	Dyeing material
Diketones	Turmeric	Direct, Mordant	Yellow, Olivine	Root, Stems
	Curcuma	Direct, Mordant	Yellow, Orange	Leaves, Stems
Naphthoquinones	Henna	Mordant, Dispersion	Yellow	Flower, Leaves, Stems
	Comfrey	Mordant	Purple	Root
	Walnut	Mordant	Brown, Black	Bark
Anthraquinones	Rhubarb	Mordant, Dispersion	Yellow	Root, Stems
	Madder	Mordant, Dispersion	Red, Black	Root, Stems
Carotenoids	Gardenia	Direct, Mordant	Yellow, Grayish yellow	Fruitage
	Annatto	Direct	Yellow	Peel
	Saffron	Direct	Yellow	Flower
	Rosewood	Direct	Yellow	Bark
Indoles	Indigofera	Reduction	Blue	Leaves, Stems
	Strobilanthes cusia	Reduction	Blue	Leaves, Stems
	Indigofera	Reduction	Blue, Green	Leaves, Stems
	Isatis indigofera	Reduction	Blue	Leaves, Stems
Alkaloids	Daylily	Direct, Mordant, Cation	Yellow	Bark, Leaves
	Coptis chinensis	Direct, Mordant, Alkaline	Yellow	Root, Stems
Polyphenols	Pomegranate	Direct, Mordant, Acidic	Yellow, Brown	Peel, Root
	Gallnut	Mordant	Yellow, Brown, Black	Insect parasites
	Betel nut	Mordant	Black	Fruitage
	Chestnut	Direct, Mordant	Black, Brown	Bark
Pyrans	Sappan	Mordant	Red, Yellow, Purple, Black	Root, Stems
	Tea	Direct, Mordant	Brown	Leaves
	Ginkgo Leaf	Direct, Mordant	Yellow, Brown	Leaves

1) Direct dyes are suitable for cellulose fiber fabrics. They have poor washing fastness and different light fastness, but the washing color of modified direct dyes will be greatly improved [10].
2) Reactive dyes are mostly used for cellulose fiber fabrics and less for protein. They are characterized by bright color, light fastness, good washing and friction resistance.
3) Acid dyes are mostly suitable for protein fibers, nylon fibers, and silk. They are characterized by bright color, poor washing fastness, excellent dry cleaning resistance, and are widely used in natural dead dyeing [11].
4) Azo dyes (naphtho dyes) are suitable for cellulose fabrics. They have bright colors and are more suitable for bright colors [12].
5) Cationic dyes are suitable for acrylic, polyester, nylon and fiber and protein fibers. They are characterized by bright colors and are very suitable for artificial fibers, but the washing and light fastness color of natural cellulose and protein fabrics are very poor [13].
6) Sulfur dyes are suitable for cellulose fiber fabrics. They are dark in color, mainly navy blue, black and brown. They have excellent light and water resistance, but

poor resistance to chlorine bleaching. Long-term storage of fabrics will damage the fibers [14].

Natural plant dyes are non-toxic and harmless, non-allergenic and non-carcinogenic to the skin. They have good biodegradability and environmental compatibility. They have soft colors and natural characteristics, and have broad development prospects in the fields of high-end silk products, home textile products, decorative items, and ethnic costumes [15].

2. Methods

2.1. Extraction of dye liquor—boiling juice—branches and leaves type as an example

For the extraction process, dye materials such as Fumu and Jiuxiong are used at about 2–3 times the weight of the dyed material. Yam, being more efficient, is used at about 0.5–1 times the weight. Tiger claw bean is typically used at 2–3 times the weight for the initial dyeing. The dye materials are washed, chopped, and placed in a stainless steel pot. They are then boiled over high heat to extract the pigment. After the water reaches a boil, it is maintained for 30 min, followed by cooking at medium heat for another 50 min, with the extraction process repeated 2–3 times.

2.2. The stable biological dye and technical solution of this study

The following raw materials are used in specific mass percentages:

Trinitrophenol: 1%–15%;

Sodium persulfate: 2%–30%;

Acrylate: 3%–25%;

Medical-grade acetic acid: 1%–15%;

5,6,7,8-Tetrahydrofolate: 0.5%–15%;

Horseradish peroxidase: 0.1%–5%;

Formalin: 1%–10%;

Ethanol: 1%–30%;

The balance is deionized water.

Various formulations of the stable biological stain include:

Formulation 1: 2%–12% trinitrophenol, 4%–25% sodium persulfate, 5%–22% acrylate, 2%–12% medical-grade acetic acid, 1%–12% 5,6,7,8-tetrahydrofolic acid, 0.5%–4% horseradish peroxidase, 2%–8% formalin, 2%–25% ethanol, with the balance being deionized water.

Formulation 2: 4%–10% trinitrophenol, 5%–22% sodium persulfate, 7%–20% acrylate, 4%–10% medical-grade acetic acid, 2%–10% 5,6,7,8-tetrahydrofolic acid, 0.8%–3% horseradish peroxidase, 3%–7% formalin, 5%–20% ethanol, with the balance being deionized water.

The formaldehyde content in formalin is maintained at 1%–5%.

3. Preparation method of the biological stain

1) Combine trinitrophenol, sodium persulfate, medical-grade acetic acid, and deionized water. Mix thoroughly, allow the mixture to stand and settle, then decant the supernatant to obtain Mixture A.
2) Mix Mixture A with acrylate, 5,6,7,8-tetrahydrofolic acid, horseradish peroxidase, and ethanol. Heat the mixture in a water bath at 30 ℃–80 ℃ for 5–50 min, adding formalin during the heating process. Stir the mixture evenly to produce the biological stain.

   Additional Notes:

   The standing time in step 1 is between 1–24 h.

   The upper clear liquid in step 1 is filtered using qualitative filter paper.

   In step 2, the mixture is placed in a water bath at 40 ℃–70 ℃ for 8–40 min.

   The stirring speed in step 2 is maintained at 60–300 r/min.

24 mg of PVP was dissolved in 0.5 mL of N-butylpyridinium tetrafluoroborate BF4 ionic liquid under magnetic stirring, and then 0.12 mL of 3.67 mol/L NaBH4 biological dye aqueous solution was added at room temperature. The above solution is marked as biological staining solution A. 6 mg TeO2 and 1 mL of ionic liquid of N-butylpyridinium tetrafluoroborate BF4 are mixed evenly under magnetic stirring at room temperature, and the solution is marked as biological staining solution B. Solution A was heated to 180 ℃. using microwaves (high-focus single-mode microwave reactor, manufactured by CEM, USA), and biological staining solution B was immediately added dropwise at 180 ℃. The solution was kept at 180 ℃. for 10 min. Stop microwave heating and cool the solution to room temperature. Separate the product by centrifugation, wash the separated product with anhydrous ethanol for 3 times, and then wash it with distilled water for 2 times. Finally, dry it in vacuum at 60 ℃. The diameter of the dyed nanotextile wire is 20–100 nm.

a) At least one room temperature ionic liquid selected from the following ionic liquids composed of cations and anions; the cation is one of N-alkylpyridinium ion $[RPy]^+$, N, N1-dialkylimidazolium ion $[RR'IM]^+$, alkylquaternary ammonium ion $[NR_1R_2R_3R_4]^+$ or alkylquaternary phosphonium ion $[PR_1R_2R_3R_4]^+$; the anion is one of BF_4^-, PF_6^-, CF_3COO^-, $C_3F_7COO^-$, $CF_3SO_3^-$, $C_4F_9SO_3^-$, $(CF_3SO_2)_2N^-$, $(C_2F_5SO_2)_2N^-$, $(CF_3SO_2^-)_3C^-$, SbF_6^-, AsF_6^-, $CB_{11}H_{12}^-$, NO_2^-.
b) Selecting reactants according to the type of prepared nanopowder, including oxides, metal salts, alkaline substances or sulfur-containing compounds; adding the reactants to a room temperature ionic liquid to form a uniform solution or suspension, and the concentration of the reactants is 0.001–10 mol/L; or one or more reactants are first dissolved in distilled water or deionized water to prepare an aqueous solution, and then added to the ionic liquid at a certain temperature, and the concentration of the reactants is also 0.001–10 mol/L;
c) Or adding at least one surfactant or stabilizer as needed, the concentration of which is less than 10 mol/L; placing the biological dye liquid phase reaction system prepared in the step in a microwave field and heating it at 40 ℃–300 ℃ for 2 min–2 h, wherein the specific heating power, heating time and temperature are determined according to the prepared nanomaterial.

We will modify the Yao pattern fabric dyed with nano-natural dyes in the following steps:

1) Prepare a finishing solution with the components of 20–160 g/L organic carboxylic acid compound, 5–60 g/L catalyst, and 0.5–5 g/L penetrant, and adjust the pH value of the finishing solution to 2.0–3.5;
2) Perform two immersion and two rolling treatments on the Yao pattern fabric in the above finishing solution, with a rolling rate of 60%–100%;
3) Pre-bake at 80 ℃–100 ℃ for 2–6 min;
4) Bake at 100 ℃–180 ℃ for 1–5 min.

The organic carboxylic acid compound is one of hydroxy dibasic acid, polybasic acid, polycarboxylic acid or a mixture thereof; the nano-hydroxyphosphate material was successfully loaded onto the biological surface. When the loading ratio was 105:1 (W/W BC: N-HAP), the amount of the composite material used was 30 mg, and the system pH was 9, the removal rate of rhodamine B was 89.8% within 60 min.

The dyeing-before-mordanting method is to mordant first and then dye. The order is: Mordant → washing → dyeing → washing → drying. Whether it is the dyeing-before-mordant method or the mordant method, it can be performed once or repeatedly several times as needed. The dyeing-before-mordant method has a high dyeing concentration. The dyeing-before-mordant method has good uniformity.

This study selected organic carboxylic acid compounds that can lose water under the action of heat and catalyst to form cyclic anhydrides. The generated cyclic anhydrides undergo cross-linking reactions with hydroxyl groups and other groups in natural dye molecules that are easily photosensitized to form ester groups, thereby improving the light stability of natural dyes. At the same time, it can also undergo cross-linking reactions with active groups such as hydroxyl and amino groups in fiber molecules, reacting natural dyes with fibers. The dyes and fibers are connected by covalent bonds, which enhances the binding force between the dyes and fibers and improves color fastness.

4. Result

4.1. Preparation of blue dyeing liquid

Collect indigofera leaves around the beginning of autumn and pound them.

Place 40 kg of the crushed material into a jar, add 0.7 kg of fresh Artemisia serrata flowers, and 80 kg of water (soaking about two-thirds of the crushed material), and stir to mix.

Allow the mixture to ferment naturally, stirring frequently. Fermentation occurs over 2 days at a maximum temperature of 30 ℃.

Boil the fermented liquid and simmer for 3 min on low heat to solidify it further, then filter out the residue to obtain the original dyeing liquid.

4.2. Preparation of yellow dyeing liquid

Collect the leaves of the plant before and after the White Dew Festival, and pound them into small pieces.

Take 50 kg of the small pieces, add 0.5 kg of fresh Artemisia selengensis flowers, and 100 kg of water to soak about two-thirds of the leaves, then stir to mix.

Allow the mixture to ferment, stirring frequently. Fermentation occurs over 3 days at a maximum temperature of 20 ℃–25 ℃.

Filter the residue to obtain the original dyeing liquid.

4.3. Preparation of red dyeing liquid

Take the roots and vines of small-fruited roses that have grown for more than 3 years, break them with a hammer, remove the old outer shell, and pound them into pieces.

Take 8 kg of the pieces, add 0.2 kg of gallnut fruit, and 10 kg of water, covering about two-thirds of the pieces, then stir to mix.

Boil for 5 min and filter the residue to obtain the original dyeing liquid.

4.4. Preparation of dyeing liquid

Combine one or more of the above-prepared blue, yellow, and red dyeing liquids in proportion to prepare the original dyeing liquid of the required hue.

4.5. Nanotechnology treatment

After nanotechnology treatment according to the production process, the dyeing liquid can be utilized.

Natural Nano Pigments:

High solubility in water and can be adsorbed by fibers. To improve firmness, mordant dyeing is required.

Almost insoluble in water; their glycosides are soluble in water and are adsorbed by fibers, then fixed by post-mordant dyeing.

Low solubility in water and contain chelate coordination positions, forming coordination bonds with metal ions adsorbed on fibers through mordanting, thus fixing the dye.

Exist in plants as natural nano pigments and form insoluble pigments on fibers during the dyeing process. Nano homogenization technical parameters: The processing pressure can reach up to 207 MPa (30,000 PSi), it can work continuously for 24 h at 207 MPa, the flow rate is 2.1 L/h, the inlet temperature can reach 80 degrees, the outlet temperature can be controlled below 30 degrees, and the material can be cut off, empty, started, stopped, and paused during high-pressure operation.

5. Discussion

5.1. EU standard for color fastness to washing

The EU standard for color fastness to washing is specified by ISO 105-C06-2010, "Textiles—Tests for color fastness—Part C06: Color fastness to domestic and commercial washing". This test involves subjecting textile samples and the specified standardized lining fabric combinations to a series of washing, rinsing, and drying processes.

Washing is conducted under controlled conditions, which include appropriate temperature, alkalinity, bleaching, and friction. The friction effect is moderated by using a low bath ratio and a specific number of stainless steel balls.

5.2. Test specifications

The size of the test piece and the lining is standardized to (100 ± 2) mm × (40 ± 2) mm. The lining fabrics used in the test include single fiber linings and multi-fiber linings, denoted as DW for low-temperature lining and TV for high-temperature lining.

5.3. Lining fabric details

The first single fiber lining is composed of the same fiber as the test sample, ensuring consistency in the test conditions. The second single fiber lining is made from materials listed in the corresponding table. For blended or interwoven product samples, the first piece of lining is made from the main fiber content, while the second piece is made from the lesser fiber content. This arrangement ensures that the color fastness of all fiber types in the sample is adequately tested. (See **Table 2** and **Table 3**)

Table 2. Nano-bio-dyed Yao pattern textile test.

Test number	Temperature ℃	Liquor volume mL	Available chlorine %	Sodium perborate g/L	Time min	Number of steel balls	Adjust pH to
A1S	40	150	None	None	30	10a	Not adjusted
A1M	40	150	None	None	45	10	Not adjusted
A2S	40	150	None	1	30	10	Not adjusted
B1S	50	150	None	None	30	258	Not adjusted
B1M	50	150	None	None	45	50	Not adjusted
B2S	50	150	None	1	30	25a	Not adjusted
C1S	60	50	None	None	30	25	10.5 ± 0.1
C1M	60	50	None	None	45	50	10.5 ± 0.1
C2S	60	50	None	1	30	25	10.5 ± 0.1
D1S	70	50	None	None	30	25	10.5 ± 0.1
D1M	70	50	None	None	45	100	10.5 ± 0.1
D2S	70	50	None	1	30	25	10.5 ± 0.1
D3S	70	50	15	None	30	25	10.5 ± 0.1
D3M	70	50	15	None	45	100	10.5 ± 0.1
E1S	95	50	None	None	30	25	10.5 ± 0.1
E2S	95	50	None	1	30	25	10.5 ± 0.1

Quality of fabrics dyed with natural plant dyes:

1) Color difference ≥ 3.5 (GB/T7921-2008).
2) Soap washing color fastness ≥ 3.5 (GB/T3921-2008).
3) Color fastness to perspiration: Acid sweat ≥ 3.5 level alkali sweat ≥ 3.5 level (GB/T3922).

4) Color fastness to abrasion: Dry abrasion ≥ 3.5 level wet abrasion ≥ 2.5 level (GB/T3920).
5) Color fastness to light ≥ 3 level (GB/T8427-2008).
6) Color fastness to saliva ≥ 3 level (GB/T18886-2002).

Table 3. Nano natural dye details.

Item	**Staining depth**	**Solubility**	**Souping**		**Rubbing**		**Acid**		**Chlorine water resistant**		**Alkali**		**Water Rubbing**		**Xenon Light**
			CH	**CO**	**Dry**	**Wet**	**CH**	**CO**	**20 P pm**	**50 p pm**	**CH**	**CO**	**CH**	**CO**	
Reactive Yellow	2.0	80	3–4	4–5	4	4–5	4	4–5	4–5	4–5	4–5	3–4	1–2	4–5	4–5
Reactive Red	2.0	200	3–4	4	4–5	4–5	4	4–5	4	4	4	3–4	3	4–5	4
Active Green	2.0	200	3–4	4	4	4–5	3–4	3–4	4–5	3–4	4–5	2–3	1–2	4–5	4
Active Golden	20	200	4	4–5	4	4–5	4	4–5	4–5	4–5	4–5	3–4	2	4–5	4
Reactive Brilliant Red	2.0	150	3–4	4	4	4–5	3–4	4	4	4	4	3–4	2–3	4	4
Active Navy Blue	2.0	200	2–3	3–4	4	4–5	3	4	4	4	4	4	3	4	4
Active Super Yellow	2.0	200	3–4	4–5	4–5	4–5	4	4–5	3–4	4–5	3–4	4	3–4	4–5	4
Active Super Red	2.0	150	3–4	4–5	4	4–5	3	4	4	4	4	3–4	3	4–5	3–4
Active Super Navy	2.0	200	2–3	4	4	4–5	3	4	3–4	4	3–4	4	3	4–5	3
Active Super Green	2.0	150	4–5	4–5	4–5	4–5	3–4	4–5	4–5	4–5	4–5	3–4	2–3	4–5	4–5
Reactive Super Magenta	2.0	150	3–4	4	4	4–5	3	4–5	4	4–5	4	4–5	4	4–5	4
Active Super Black	8.0	200	2–3	4	3–4	4–5	2–3	4–5	3–4	4–5	3–4	3–4	2–3	4–5	4

5.4. Dyeing example—red dyes

When using madder to dye, the process begins by adding madder roots to 30 ℃ warm water, followed by the pre-mordanted Yao pattern fabric. The temperature of the dye solution is gradually raised to 100 ℃. After dyeing for 1 to 1.5 h, the temperature is immediately reduced to 90 ℃, and dyeing continues for an additional 0.5 h with regular stirring [3]. Once the desired color is achieved, the Yao pattern fabric is cooled in the dye solution, then rinsed in warm water followed by cold water, and finally dehydrated and dried. Rubiatin forms complexes with mordants on fibers to create insoluble metal complex dyes. When used for dyeing cotton fabrics, it results in a bright red color [5].

5.5. Advantages of nano-natural biological dyeing

Compared to existing technologies, nano-natural biological dyeing offers several advantages:

1) Modification with organic carboxylic acid compounds: These compounds modify natural dye-dyed fabrics by cross-linking with hydroxyl groups in natural dye molecules that are prone to photosensitization, thereby improving the light stability of natural dyes. This process generally enhances the light fastness of natural dye-dyed fabrics by 1 to 2 levels.

2) Enhanced bonding and durability: During the modification process, organic carboxylic acid compounds cross-link with dyes and active groups such as hydroxyl and amino groups in fiber molecules. This covalent bonding strengthens the attachment between the dye and fiber, improving the washing fastness and overall durability of the dyed fabric.
3) Ecological benefits: The use of organic carboxylic acid compounds and the entire treatment process do not produce free formaldehyde or other harmful substances, meeting the requirements for ecological textiles.

6. Conclusion

We use nano-natural dyes to dye fabrics and then modify them. First, we prepare a finishing solution with the components of 20–160g/L organic carboxylic acid compounds, 5–60g/L catalysts, and 0.5–5g/L penetrants. We then perform two-immersion and two-rolling treatments on the Yao pattern fabrics in the above finishing solution, and then pre-bake and bake them. After testing, the treated Yao pattern fabrics can improve their sunlight fastness by 1–2 levels. Under the action of heat and catalysts, water is lost to generate cyclic anhydride organic carboxylic acid compounds. The generated cyclic anhydride undergoes a cross-linking reaction with the hydroxyl and other groups in the natural dye molecules that are prone to photosensitization to form ester groups, thereby improving the light stability of the natural dye. At the same time, we can also undergo a cross-linking reaction with the hydroxyl, amino and other active groups in the fiber molecules to improve the washing fastness of the dyed Yao pattern fabrics and have good durability [16]. (see **Figure 1**)

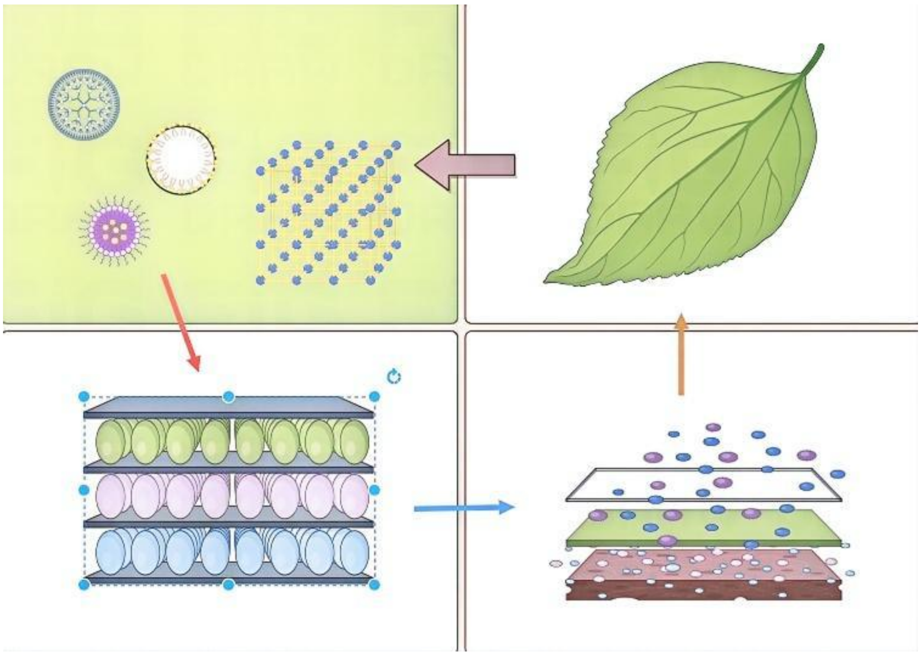

Figure 1. Nano-bio-dye materials organic recycling.

Nanobiomaterials originate from nature and will eventually return to nature after biodegradation.[17] Natural plant dyes are generally non-toxic, harmless, non-allergenic and non-carcinogenic to the skin, have good biodegradability and environmental compatibility, and are abundant in resources. Some natural plant dyes come from medicinal plants, which themselves have certain health benefits. After adding the auxiliary agent (CWL), there is no obvious adsorption saturation value on the adsorption isotherm, the adsorption rate of the dye to the fiber increases, and the adsorption saturation value of the disperse dye in the polyester fiber also increases [18]; However, there are also many problems with using natural dyes, mainly the following three points: 1) The content of natural plant dyes is low, and a large amount of plants are consumed during extraction, which is not conducive to environmental protection. The treatment of plant waste after extraction is also a problem, and the cost is also high; 2) except for a few, most natural plant dyes have poor color fastness, and even with the use of mordants, the fastness is still not ideal. Moreover, many natural plant dyes will change color or become gray during washing and use. Especially when mixing colors, the color change is more obvious due to the large difference in fastness of different plant dyes. Many plant dyes have multiple ligands such as hydroxyl groups, which can complex with metal ions to form chelates. Although some metal ions can be used as mordants to improve the water fastness of natural pigments, the fastness of many metal ions after complexation is not ideal; 3) except for a few, most natural plant dyes have poor color fastness, and even with the use of mordants, the fastness is still not ideal. Moreover, many natural plant dyes will change color or become gray during washing and use. Especially when mixing colors, the color change is more obvious due to the large difference in fastness of different plant dyes. After adding anionic surfactant (ALS), it has a certain solubilizing effect on disperse dyes, which increases the amount of single-molecule disperse dyes in the dye solution. As a result, the dyeing rate of disperse dyes on polyester fibers is greatly reduced due to the limitation of the molecular size of disperse dyes in the dye solution, and dyeing equilibrium is reached in about 10 min [18]. Many plant dyes have multiple ligands such as hydroxyl groups, which can complex with metal ions to form chelates. Although some metal ions can be used as mordants to improve the water fastness of natural pigments, the fastness of many metal ions after complexation is not ideal.

The nanobio-dyes market is undergoing a major transformation driven by technological innovations and shifting consumer preferences. The industry is highly focused on sustainable development and emerging market opportunities, offering a bright future for businesses. Keeping up with the latest trends and advancements in nanobio-dyes is essential to fully tap into the growth potential of this dynamic and evolving market.

Limitations: Due to material factors, this solution cannot be implemented in mass industrial production for the time being. Parts of this experiment (e.g., extraction, mixing, and staining steps) can be automated.

Ethical approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Hezhou University (protocol code HZU/CAF/GUANGXI/2022/6 and 11/25/2014 of approval).

Conflict of interest: The author declares no conflict of interest.

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