Scientific and Social Research, 2026, Volume 8, Issue 6
http://ojs.bbwpublisher.com/index.php/ssr
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Research on the Application of Natural Pigment from Mugwort in the Dyeing of Ramie Fibers

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Abstract: Under the strategic goal of "Dual Carbon", China's textile industry is gradually transforming toward green, environmentally friendly, and sustainable development, and natural plant pigments are being increasingly applied in the textile industry. As a traditional medicinal plant in China, mugwort contains flavonoid-based natural pigments that can be used for fabric dyeing to further improve color fastness and color uniformity. Ramie is a kind of natural fiber featuring outstanding air permeability and antibacterial properties; nevertheless, its high crystallinity leads to great difficulties in dyeing. At present, the application of natural mugwort pigment in ramie dyeing is still limited, which restricts the dyeing effect of ramie fibers. This paper mainly analyzes the extraction technologies of natural mugwort pigment and the pretreatment processes of ramie fiber for dyeing, and explores the application of natural mugwort pigment in ramie fiber dyeing, so as to improve the overall dyeing performance of ramie fibers.

Keywords: Mugwort; Natural pigment; Ramie fiber; Dyeing process

Online publication: July 15, 2026

1. Introduction

Although chemical and synthetic dyes feature a uniform dyeing effect and favorable color fastness, they will not only cause environmental pollution but also easily trigger human allergic reactions and skin diseases, posing prominent challenges to the development of the textile industry. Against such a backdrop, natural plant dyes have become a hot research topic in the textile field. As a traditional Chinese herbal medicine, mugwort contains natural pigments as well as anti-allergy and antibacterial health-care properties. When adopted for ramie dyeing, it can guarantee the color rendering property and color fastness of ramie while avoiding human allergic symptoms. Researchers need to further optimize the extraction process of natural mugwort pigment to prepare dye liquor with superior color rendering capacity, coloring performance, and color fastness. Meanwhile, pretreatments shall be conducted on ramie fibers to facilitate the adhesion of natural pigments onto ramie fibers and ensure uniform dyeing. In addition, orthogonal experiments should be optimized to define technical parameters of dyeing processes and improve mordanting processes, so as to comprehensively boost ramie dyeing effect and advance the high-quality development of the textile industry.

2. Extraction processes of natural pigment from mugwort

2.1. Microwave-assisted extraction method

Microwave-assisted extraction is an innovative pigment extraction technology. High-frequency microwave penetrates into mugwort tissues to destroy internal plant cell structures and generate intense molecular motion, thus breaking cell walls, accelerating the precipitation of natural pigment components inside mugwort, and enhancing the extraction purity of natural mugwort pigment to prepare high-concentration dye liquor. Characterized by high extraction purity and intelligent controllability, this extraction method boasts broad application prospects [1]. Under laboratory conditions, technicians take water as the extraction solvent with the solid-liquid ratio of raw material to solvent set at 1:15, microwave power adjusted to 560W, and operation time controlled around 2 minutes. Such parameter settings enable the microwave to fully break down mugwort tissues and raise the extraction efficiency and purity of mugwort pigment.

2.2. Water bath extraction method

Water bath extraction ranks as the most conventional method for natural pigment extraction, with the merits of low cost and easy operation. However, precise control over reaction duration and temperature remains difficult, resulting in excessive impurities, low dye liquor purity, and unstable quality of natural pigment solution. In laboratory tests, deionized water with a pH value of 7 is selected as the solvent at a solid-liquid ratio of 1:20 and heated to 60°C for pigment extraction. During the experiment, technicians shall monitor heating temperature strictly to prevent water temperature from exceeding 70°C, since excessively high temperature will damage mugwort cell structures and impair pigment extraction. Besides, solvent concentration and pH value shall be regulated to keep pH below 8 for pigment stability and avoid discoloration of mugwort pigment liquor, thereby promoting the purity and stability of extracted natural mugwort pigment [2].

2.3. Combined extraction method of organic solvent and ultrasonic treatment

To improve the extraction purity of natural mugwort pigment and the stability of resultant dye liquor, technicians combine organic solvent extraction with ultrasonic treatment to extract chlorophyll and flavonoid natural pigments contained in mugwort to the maximum extent. Absolute ethyl alcohol is adopted as the extraction agent for natural mugwort pigment, and response surface methodology experiments are carried out to confirm the solid-liquid ratio and ultrasonic processing time, so as to precisely control dye liquor concentration and extraction duration and strengthen the pH stability of the extracted natural mugwort pigment solution.

3. Pretreatment processes of ramie fibers before dyeing

3.1. Physical and biochemical pretreatments

Ramie fiber features a smooth surface and high crystallinity with scarce active groups on cell structures, which creates strong binding resistance against dye molecules and leads to difficult dyeing and poor color fastness. Pretreatments, including physical and biochemical treatments on ramie fibers, are required to facilitate the attachment of natural mugwort pigment molecules and upgrade the color rendering property and color fastness of dyed ramie [3]. Firstly, technicians soak ramie fibers in a dilute sulfuric acid solution at 50–60°C to remove surface impurities and colloids and soften ramie fibers via physical treatment. Secondly,

ultrasonic treatment with specific frequency and power is applied to eliminate deep-layer colloids inside ramie fibers and increase fiber surface roughness, enabling firmer adhesion of natural mugwort pigment onto ramie fibers.

3.2. Chemical modification via cationization

Cationization pretreatment on ramie fibers can effectively enhance the pigment adsorption capacity of fibers and optimize ramie dyeing performance [4]. Quaternary ammonium compounds are used to treat ramie fibers to trigger chemical reactions, replace intrinsic cations inside fibers, and introduce positively charged ammonium cation groups into fiber cells. Such modification accelerates the combination between flavonoid pigments in mugwort dye liquor and ramie fibers, facilitates pigment attachment, and improves the color fastness of dyed ramie fibers.

3.3. Low-temperature softening modification

Ramie fabric feels stiff, which not only brings obstacles to dyeing but also causes poor wearing comfort. Therefore, low-temperature softening modification is conducted on ramie fibers to improve dyeing performance and reduce pricking and stinging sensations during wearing, while retaining the inherent antibacterial property of ramie. Thiourea is used as a cosolvent, and ramie fibers are immersed in the solvent kept between -10°C and 1°C. Low-temperature environment rapidly destroys ramie's crystalline structure, softens fiber texture, and widens gaps among ramie fiber cells, favoring pigment attachment and diffusion inside fibers and guaranteeing uniform dyeing of ramie fibers [5].

4. Application technology of natural mugwort pigment in ramie fiber dyeing

4.1. Optimize the extraction process of mugwort pigment to improve dye liquor quality

Continuous optimization of the extraction process of natural mugwort pigment is essential to guarantee purity, concentration, and stability of extracted pigment and high-quality dye liquor for subsequent ramie dyeing. First of all, microwave technology is adopted for natural pigment extraction from mugwort. High-frequency microwave breaks mugwort cell walls and accelerates the separation of internal chlorophyll and flavonoid natural pigments to raise the pigment precipitation rate and reduce the loss of active ingredients for a higher concentration of pigment solution. Dried mugwort is taken as raw material, crushed by wall-breaking equipment, and purified to remove impurities. Single-factor experiments and orthogonal tests are performed to define optimal dye liquor matching ratio and microwave parameters [6]. According to orthogonal experiment results, the optimal solid-liquid ratio for natural mugwort pigment extraction is 1:15, microwave power is set at 560W, and microwave treatment time lasts around 2 minutes. Pigment extracted under such conditions contains fewer impurities and presents a more uniform color. Afterward, the extracted mugwort pigment solution is cooled down statically, filtered with filter screens to eliminate residues, and concentrated to the proper concentration. The prepared dye liquor is stored in a refrigerator under a neutral pH environment to avoid decomposition of chlorophyll and flavonoid pigment, as well as liquor discoloration and dyeing aberration induced by acidic or alkaline surroundings [7].

4.2. Optimize pretreatment flow of ramie fibers for uniform dyeing

Stable molecular structure and narrow intercellular gaps of ramie fibers leave limited space for natural

pigment adhesion, resulting in low dye uptake rate and unsatisfactory color fastness of mugwort pigment on ramie. Combined pretreatment of water washing, degreasing, and cationic modification is hence adopted to remove surface dirt and grease first and alter the inert surface status of ramie fibers for improved pigment attachment [8]. Technicians soak and clean ramie fibers with warm water at about 40°C to clear surface grease before cationic modification treatment, which further destroys ramie fiber cell structure and replaces original cations to promote penetration of mugwort pigment into fiber interior for efficient coloration. After cationic modification, ramie fibers are rinsed with warm water to strip the floating surface pigment and dried at a low temperature for enhanced dye color fastness [9]. Cation-modified ramie fibers have lower crystallinity and a positively charged surface, which can adsorb anionic mugwort pigment molecules tightly via electrostatic interaction to strengthen bonding fastness between pigment and ramie fibers and mitigate color fading. Moreover, cationic modification softens ramie fibers while reserving their superior air permeability, improving both dyeing effect and wearing comfort, and boosting market promotion of ramie textiles [10].

4.3. Orthogonal optimization of core dyeing technical parameters for desirable dyeing effect

Precise control over core dyeing parameters, including dyeing temperature, duration, dye liquor pH value, and pigment dosage via multiple orthogonal experiments, helps achieve uniform dyeing and high color fastness and prevent color fading and cross-staining of finished ramie products [11]. Firstly, analyze the molecular movement characteristics of mugwort pigment and the influence of high and low temperatures on molecular activity to determine the appropriate dyeing temperature. Four-factor three-level orthogonal experiments are implemented to screen an optimal overall dyeing scheme for natural mugwort pigment on ramie fibers. Mugwort pigment tends to be oxidized and decomposed under high temperature, leading to dye liquor fading; pigment molecules remain inactive under excessively low temperature and fail to penetrate into ramie fiber interior, causing heavy floating pigment and subsequent color drop [12]. Experimental data prove that pigment molecular structure stays stable and penetration rate reaches peak value at a constant temperature of 60°C with optimal overall dyeing performance. Comparative tests between weakly acidic and weakly alkaline dye liquor indicate that weakly acidic conditions deliver better dyeing effect when dyeing duration is controlled within 30 minutes. Such parameter setting softens ramie fibers to facilitate pigment infiltration, improves color rendering, reduces excess floating pigment on fiber surface, and cuts down consumption of mugwort dye liquor [13].

4.4. Optimize the mordanting process to promote color fastness

Compared with synthetic chemical dyes, natural plant pigments are restricted by insufficient color fastness and uneven coloring. The coarse and stiff texture of ramie fibers makes direct dyeing difficult to meet standard requirements for textile products. Therefore, this paper puts forward a composite mordanting process adopting eco-friendly mordants together with natural mugwort pigment to improve color fastness, rub fastness, and soap-washing fastness of dyed ramie [14]. Tannic acid pre-mordanting combined with nano titanium dioxide post-mordanting is selected to avoid heavy metal contamination on ramie fabrics and guarantee environmental friendliness. Preprocessed ramie fibers are soaked in 2g/L tannic acid solution under a constant temperature of 55°C for 15 minutes to generate more micro-pores on the fiber surface and facilitate subsequent pigment uptake. After dyeing, ramie is immersed in 1.5g/L nano titanium dioxide solution for 20

minutes of low-temperature color fixing to lock natural mugwort pigment and inhibit color loss. Post color fixing, ramie fabrics are rinsed in warm water at 45°C to wipe off surface floating pigment, followed by cold-water rinsing and drying at 55°C. High-temperature drying or sunlight exposure is forbidden to prevent fabric discoloration and fading and secure the qualified dyeing performance of ramie fibers [15].

5. Conclusion

In conclusion, natural mugwort pigment has irreplaceable advantages in ramie fiber dyeing. It retains ramie's original air permeability and antibacterial property while upgrading dyeing uniformity and color fastness and softening ramie texture, which benefits the popularization of ramie textiles and the healthy development of the textile industry. Based on comprehensive experimental data, continuous optimization of pigment extraction, fiber pretreatment, and formal dyeing processes is required. The optimal extraction conditions are a solid-liquid ratio of 1:20, an extraction time of around 90 minutes, and an extraction temperature of 85°C; the optimal formal dyeing parameters include a dyeing temperature of 85°C, a dyeing time within 60 minutes, and weakly acidic dye liquor, which effectively elevates the overall dyeing quality of ramie fibers.

Funding

Science and Technology Research Program of Chongqing Municipal Education Commission, Project No.: KJZD202313001

Disclosure statement

The authors declare no conflict of interest.

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