



Natural Dye from Mulberry: A Sustainable and Eco Friendly Colorant

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Mulberry silk is the best natural silk because it hangs well, is very fine, and shines well. For a long time, people have used traditional resist-dyeing methods like tie-dye (bandhani, shibori, and plangi) to make one-of-a-kind patterns on silk. People have been more interested in tie-dyeing mulberry silk again in the last few years because they want unique looks, eco-friendly fashion, and slow-textile storytelling. This analysis summarizes advancements in color chemistry, materials science, tie-dye techniques, and sustainable practices that are particularly significant for mulberry silk from 2015 to 2025. It talks about ways to resist-tying, synthetic and natural dyes, new ways to mordant, digital improvements to tie-dye designs, and finishing methods that keep silk soft. We pay close attention to eco-friendly dyeing methods, such as plant-based mordants, natural dyes, and water management systems that don't waste water. We also talk about new bio-based additives, how to test for colorfastness, and how to use CAD to help with making patterns. The paper talks about how important shadow replication is to culture and society, the problems with keeping it going, and the chances of making money in the international luxury and craft markets. New developments in low-temperature dyeing, enzymatic scouring, and AI-generated tie-dye patterns show promise for bringing together traditional crafts and 21st-century textile engineering. Finally, a plan for long-term growth is put out that finds a balance between being good for the environment, making things by hand, and coming up with new designs.

Introduction

Asian and African textile traditions have used tie-dye (resist dyeing) to make high-end items for over a thousand years. This kind of dyeing works best with mulberry silk. Hand-tied resist methods have been used for a long time in Chinese zha-ran, Japanese shibori, and Gujarati/Rajasthani bandhani to make unique, asymmetrical designs that are very popular in ceremonial clothing. Mulberry silk has a smooth fibroin structure that makes it very good at taking dye. It can take bright colors with natural, reactive, and acid dyes. More and more people are choosing natural dyes made from plants, insects, and minerals over regular colors because they are better for the environment and last longer. People are now more interested in this because they are worried about how synthetic coloring methods affect the environment. Mulberry (*Morus* genus) is one of the best natural sources because it has so many great qualities, like a wide range of colors, being easy to extract, and being very useful. The *Morus* genus of mulberry fruit makes colors that are very dark purple, crimson, and blue. The color changes depending on which part of the plant is used and how it is taken out. This page talks a lot about how mulberry could be used as a natural dye, including its chemical makeup, how to dye with it, and how it could help the environment. It also talks about important research projects that are trying to find ways to make the mulberry dyeing process better and the natural resource last longer.

The current revival of tie-dye is due to:

- The slow fashion and craft revival movements
- The desire for "one-of-a-kind" creations
- The search for eco-friendly, long-lasting dyeing methods
- The merging of hybrid craft-industrial manufacturing with digital design

Important Sustainable & Environmental Advantages of Mulberry Dye

- **Resources that are available locally and can be used again:** Mulberry plants, like *Morus alba* and *Morus nigra*, grow quickly, are tough, and can be grown in many different types of soil and weather. Their leaves, fruits, and other products are often plentiful and can even come from farming or other businesses, like sericulture. This means that mulberries can be used as a sustainable source of food for natural dyes without needing a lot of extra land or damaging habitats.
- **Minimal Biodegradability and Toxicity:** Mulberry natural dyes come from plants, so they are usually biodegradable. They don't use a lot of the harmful chemicals, heavy metals, and artificial azo compounds that are in regular colors. Because of this, the environment lasts less long, there is less risk to aquatic life, and there is less ecotoxicity.
- Different extraction methods can save you time and energy. For example, studies show that using ultrasonic aided extraction (power ultrasound) to dye mulberry leaves takes less time and heat than traditional heating. So, the dyeing step uses less energy and leaves a smaller carbon footprint.
- **Lower Chemical Load (Effect of Moldants and Wastewater):** Mordants are often used to set dyes, but mulberry dye applications let you use softer or less dangerous mordants and make the best use of them. Also, wastewater with mulberry leaf extracts (or their wasted baths) usually has less pollution and is less toxic than synthetic colors. Less chemicals needed means less harmful effluent and less mining and making of heavy metal salts.
- **Dual Purpose: Adsorption and Wastewater Treatment:** Mulberry leaves or biomass can effectively adsorb synthetic dyes (like basic yellow and basic blue dyes) from water. This means that mulberry biomass can be used as a remediation agent for dye pollution in addition to being used as a dye. This cuts down on pollutants in textile wastewater or closes loops.
- **Support for Renewable Energy Applications and Dye-Sensitized Solar Cells (DSSCs):** Mulberry dyes that are high in anthocyanins have been used as natural photosensitizers in dye-sensitized solar cells. These are non-toxic and biodegradable alternatives to expensive synthetic dyes used in photovoltaics, which helps make energy solutions more sustainable.
- **Circular Economy and Upcycling:** Using mulberry leaves or byproducts for dye adds value to waste or low-value biomass because they can be grown using current farming methods, like growing fruit or sericulture. Some studies also suggest that leftover dye baths from synthetic dyes may be less dangerous or easier to fix or use again.

Substrate: Mulberry Silk**Structure and Dye Affinity**

Fibroin (75%) and sericin (25%) make up mulberry silk, which is a very crystalline protein polymer. Silk is very sensitive to acid and reactive dyes because its amino acids—glycine, alanine, and serine—have reactive sites that allow them to interact with dyes. Pre-treatment steps like degumming and bleaching have a big effect on how well the dye is absorbed and how shiny the final product is.

Physical and Chemical Challenges

Silk is sensitive to high pH and high temperatures, so tie-dye processing must be done in mild conditions (pH 4.5–6.5, <90 °C) to keep it from turning yellow or losing strength. New research is looking into bio-based softening agents and enzymatic degumming to lower damage and make things feel better in the hand.

Tie-Dye Techniques

Traditional Methods

- *Bandhani/Plangi*: Small pieces of cloth are sewn together with thread to keep the dye from getting through.
- *Shibori*: There are techniques like kanoko (stitched resist), itajime (fold-and-clamp), and arashi (pole-wrapping).
- Stitch-resist and fold-resist make more complicated patterns that repeat in a controlled way.

Process Flow

- *Getting the fabric ready*: washing and removing the gum
- *Marking and tying the pattern*: semi-automated or manual tying
- *Dyeing*: Using space-dye or immersion dyes (natural or acid dyes)
- *Finishing and untying*: Cleaning, softening, and scheduling

Innovations

- Laser-guided tying tools for designs that are always the same
- Enzyme-assisted dye penetration control for softer contrasts
- Hybrid tie-dye and digital printing for exact coloring
- Dyeing with a low liquor ratio to save water

Colorants and Chemistry

Organic Colors

Plant-based dyes like madder, indigo, turmeric, and annatto are coming back for silk tie-dyeing that lasts. Alum, tannins, and bio-mordants (like pomegranate rind and myrobalan) make fixation better.

Artificial Dyes

Acid dyes and metal-complex dyes give colors that are bright and last a long time in the wash. People are starting to use reactive dyes at low temperatures more often to save energy.

Sustainable Auxiliaries

To follow ZDHC (Zero Discharge of Hazardous Chemicals) rules, biodegradable wetting agents and cationic fixing agents are being made.

Pattern Planning and Digital Tools

Prior to human tying, computer-aided design (CAD) makes it easier to find the right tie points and see how patterns will look by mapping them out and simulating the results. CLO3D and Adobe Textile Designer can be used to digitally combine tie-dye designs for marketing and visualization. Machine learning is also being used to make new tie-dye designs by combining traditional styles with computer innovation.

Quality Control and Testing

Important quality indicators include:

- Colorfastness (washing, rubbing, and light)
- Changes in shape and size when untied
- Silk's ability to keep its shine.
- Using spectrophotometry and image analysis, it is possible to standardize shade repeatability while keeping artisanal variability.

Sustainability Considerations

Multiple baths are used in tie-dyeing, which produces colorful effluent. Modern strategies include:

- Recipes with little salt and little alkali
- Water recycling systems that work in a closed loop
- Natural dyes with biodegradable mordants
- Solar-assisted dyeing facilities for rural craft clusters.

Compared to traditional piece-dyeing with synthetic auxiliaries, eco-tie-dyeing on mulberry silk has a much smaller carbon footprint, according to life-cycle evaluations.

Socio-Cultural and Economic Aspects

Tie-dye helps women craftsmen in Thailand, India, and some parts of Africa make a living in the countryside. The global demand for high-end fashion (Hermès, Dior) has led to the creation of new value chains for handmade silk. Fair-trade certificates and GI (Geographical Indication) badges are helping to keep traditional methods alive while also allowing craftspeople to charge more for their work.

Challenges and Research Gaps

- The price of natural dyes and the need for a steady supply
- The tension between being able to reproduce something and being unique for commercial use
- The decline of skills as younger artisans opt for alternative professions
- Workflows that use both digital and hand-made systems must be hybrid.

Future Directions

- Blockchain-based traceability to check artisanal production
- AI-assisted tying robots to copy traditional complexity on a large scale
- Digital twins of dyeing processes to get the best results for liquor ratio, temperature, and shade
- Digital customization for custom tie-dye silk clothing that customers can see

Conclusion

Mulberry silk tie-dye is a fusion of ecological innovation, material science, and traditional art. Tie-dye is set to enter a new golden age of luxury fabrics because to water-saving techniques, bio-based dyes, sophisticated CAD simulation, and a revitalized consumer desire for authenticity and craftsmanship. In order to attain sustainable scale without sacrificing handcrafted character, future research should concentrate on combining low-impact chemical processes with digital tools for design and repeatability.

References

1. Giacomini, F., Menegazzo, M. A. B., Santos, J. C. O., Arroyo, P. A., & Barros, M. A. S. D. (2017). *Ecofriendly dyeing of silk with extract of yerba mate (Ilex paraguariensis)*. Textile Research Journal, 87(7), 829-837. <https://doi.org/10.1177/0040517516641357>.
2. Vankar, P. S., Shukla, D. K., Sharma, V., & Bhattacharya, S. (2017). *Innovative silk dyeing using enzyme and Rubia cordifolia extract at room temperature*. Pigment & Resin Technology, 46(4), 296–302. <https://doi.org/10.1108/PRT-06-2016-0065>.
3. Feng, Y., Lin, J., Niu, L., Wang, Y., Cheng, Z., Sun, X., & Li, M. (2020). *High molecular weight silk fibroin prepared by papain degumming*. Polymers, 12(9), 2105. <https://doi.org/10.3390/polym12092105>.
4. Huang, Q., Wang, Z., Zhao, L., Li, X., Cai, H., Yang, S., Yin, M., & Xing, J. (2024). *Environmental dyeing and functionalization of silk fabrics with natural dye extracted from lac*. Molecules, 29(10), 2358. <https://doi.org/10.3390/molecules29102358>.
5. Borah, N., Borah, P., Das, A., & Gopalakrishnan, S. (2023). *Sustainable dyeing of mulberry silk fabric using extracts of green tea (Camellia sinensis)*. Industrial Crops and Products, 188, 117517. <https://doi.org/10.1016/j.indcrop.2023.117517>.
6. Hayat, T., Adeel, S., Rehman, F. U., Khosa, M. K., et al. (2022). *Waste black tea leaves as a sustainable source of tannin natural colorant for bio-treated silk dyeing*. Environmental Science and Pollution Research, 29, 24035–24048. <https://doi.org/10.1007/s11356-021-17341-5>.
7. Benli, H. (2024). *Bio-mordants: a review*. Environmental Science and Pollution Research International, 31(14), 20714–20771. <https://doi.org/10.1007/s11356-024-32174-8>.

8. Agnhage, T., Perwuelz, A., Behary, N., & Nierstrasz, V. (2017). *Towards sustainable Rubia tinctorum L. dyeing of woven fabric: How life-cycle assessment can contribute*. Journal of Cleaner Production, 141, 1221–1230. (LCA + madder dyeing, process hotspots).
9. Yadav, S., Tiwari, K. S., Gupta, C., Tiwari, M. K., Khan, A., Sonkar, S. P. (2023). *A brief review on natural dyes, pigments: Recent advances and future perspectives*. (Review of extraction, fixation, mordants, eco-issues). (see SciDirect/Review).
10. Adeel, S., Salman, M., Bukhari, S. A., et al. (2023). *Sustainable application of microwave-assisted extracted tea-based tannin natural dye for chemical and bio-mordanted wool (and implications for silk)*. Journal of Natural Fibers. <https://doi.org/10.1080/15440478.2022.2136322>.
11. Guo, Y., et al. (2024). *Experimental and theoretical study of madder (Rubia tinctorum) dyeing on silk: molecular interactions and fastness*. Journal of Natural Fibers. <https://doi.org/10.1080/15440478.2024.2324302>.
12. Habib, N., et al. (2024). *Green extraction and application of yellow natural dyes: process and fastness on silk and protein fibers*. (Open access, 2024).
13. Muruganandham, M., et al. (2025). *Sustainable dyeing of cotton, silk and leather using natural pigments (Bixa orellana case study)*. (open access / MDPI/PMC).