Building a Dye Library for Sustainable Fashion

A Visual Traffic-Light System

A practice-led research exploring sustainable dye evaluation and visual guidance for designers.

Yu Shen, MA Innovative Fashion Production, LCF2025

CONTENTS

INTRO

Aim: This study aims to build a practice-led dye-method library covering natural, synthetic and bio-based systems, and to develop a designer-facing traffic-light recommendation tool for low-impact colour selection.

Objectives:

1. Document and classify key dyeing methods.
2. Evaluate methods across water use, toxicity, biodegradability, colourfastness and scalability.
3. Translate findings into a practical traffic-light scoring system and a simple prototype for designer use.

Research Background

- Environmental Challenges in Textile Dyeing

The textile dyeing industry is one of the largest sources of industrial water pollution, accounting for over 20% of global wastewater. Weak regulation and outdated dyeing practices in many regions lead to excessive chemical discharge.

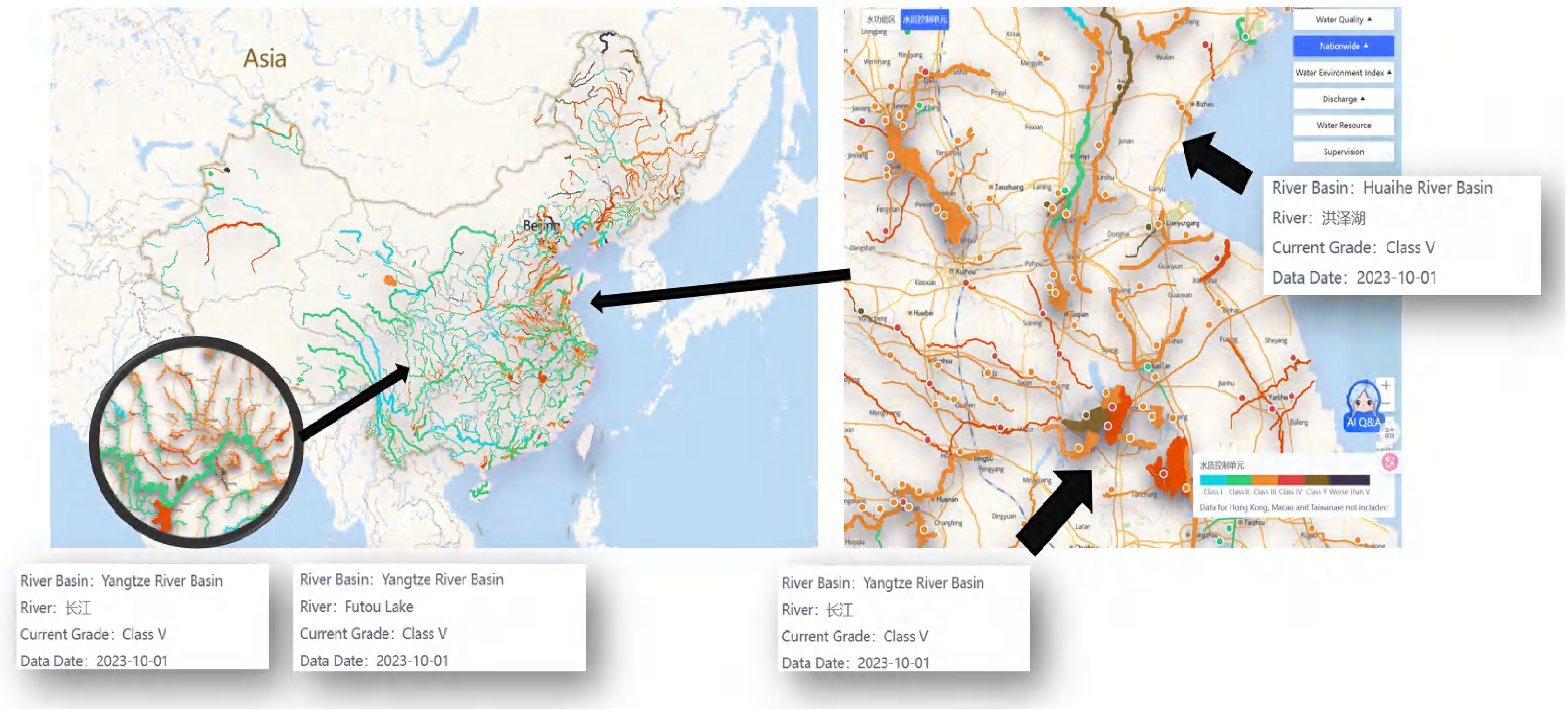


Figure 1. Data: IPE, accessed 15 Nov 2025.

In China, a major hub of global textile production, weak environmental enforcement has led to numerous violations.
The IPE (institute of Public & Environmental Affairs) water pollution map highlights dyeing factories with excessive discharges, especially in Jiangsu and Zhejiang provinces.

- Industry Perspective (Factory Insight)

Quote: My dye evaluation must be grounded in practical industry realities, not only environmental theory.

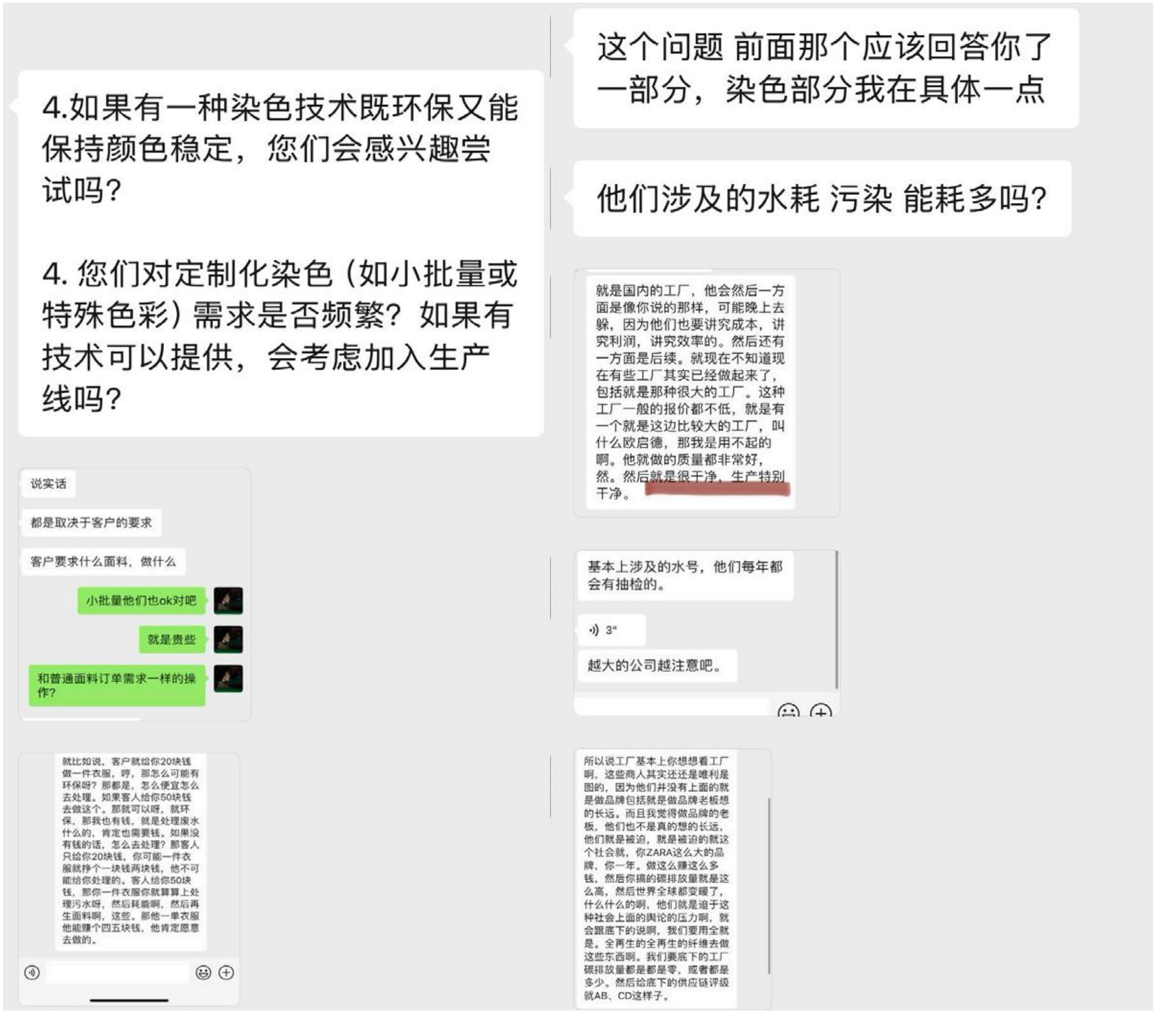


Figure 2. Data: WeChat communication with factory representative, 15 Nov 2025.

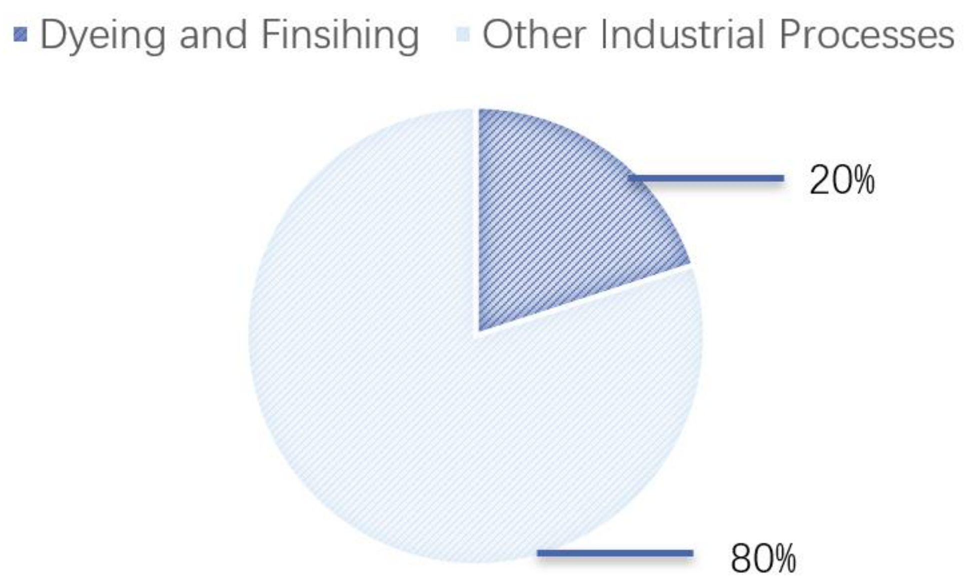
Key Q and A:

1. Client eco-dyeing decisions rely heavily on cost.
2. Small factories rarely adopt sustainable dyeing without brand enforcement.
3. Regulations alone are not effective.

Industry Dye Landscape

- Water use and pollution from textile dyeing

Industrial Water Pollution

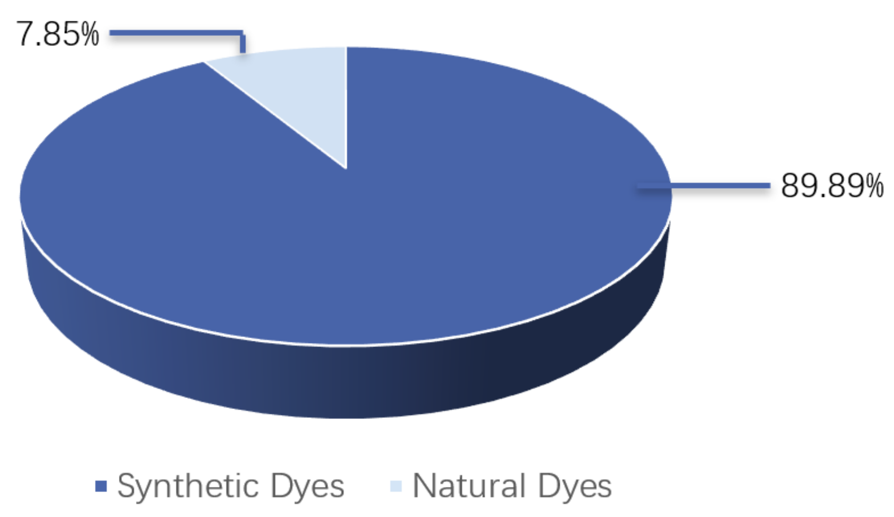


- Table 1. Data: European Parliament, 2020.

Table 1 shows that dyeing and finishing account for about 80% of industrial water pollution.

- Global textile dye usage by type

Global Textile Dyes Market

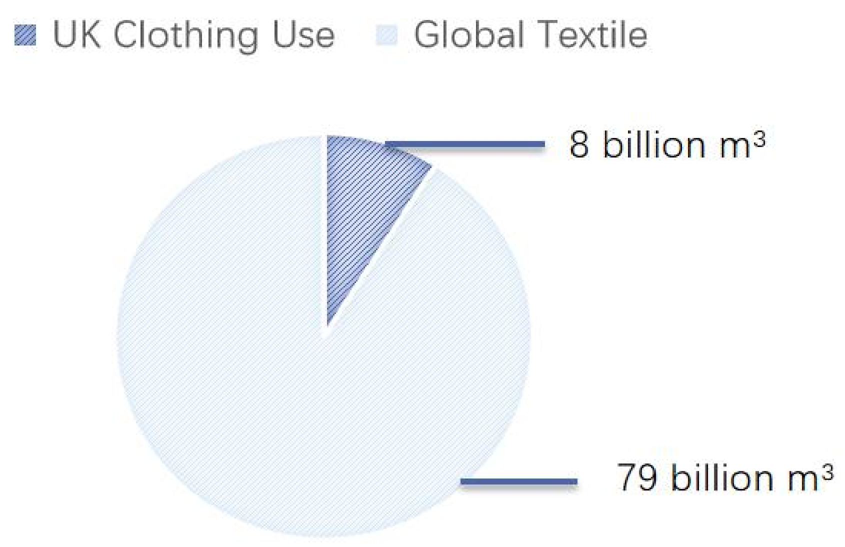


- Table 3. Data: Astute Analytica, accessed 15 Nov 2025.

Table 3 shows synthetic dyes dominate over 90% of the market, while natural dyes (8%) are growing with sustainability trends.

Evaluation :
To compare these pathways in a designer-friendly way, this project uses five evaluation criteria: water use, toxicity, biodegradability, colourfastness and scalability. These criteria later feed into the traffic-light scoring system.

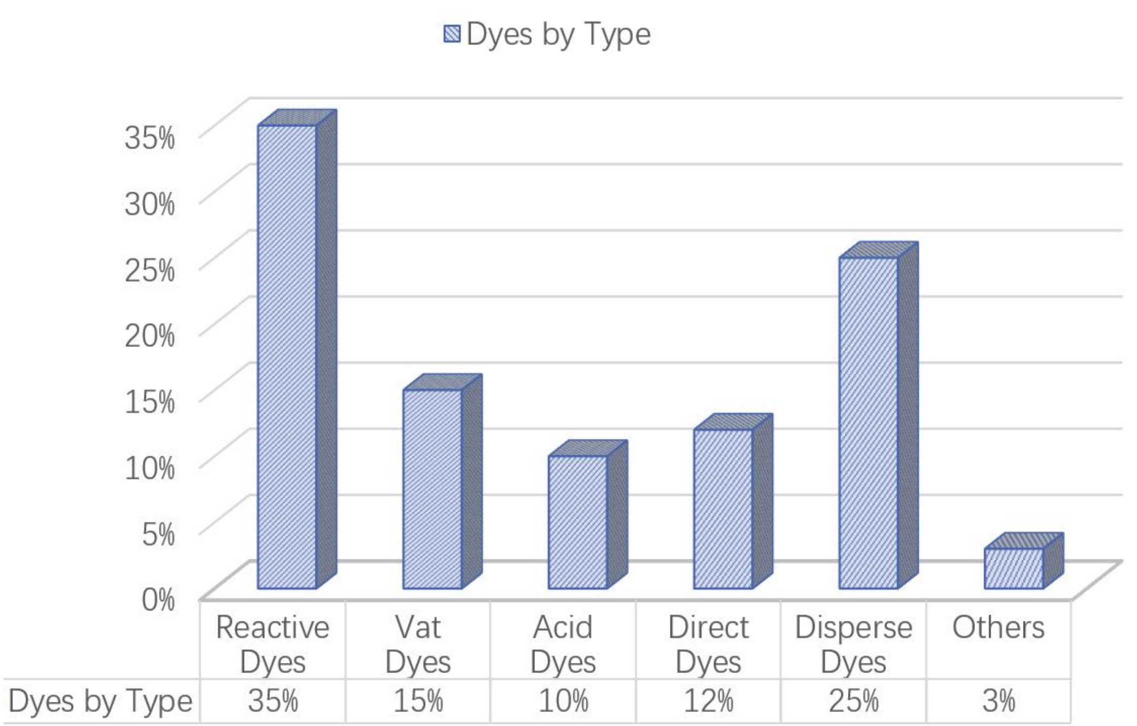
UK VS World Textile Water Use



- Table 2. Data: UK Environmental Audit Committee, 2019.

Note: the 8 bn m^3 refers to the UK's total clothing-use water footprint (all life-cycle stages), and 79 bn m^3 to global fashion industry total water use.

Dyes by Type



- Table 4. Data: Global Growth Insights, accessed 15 Nov 2025.

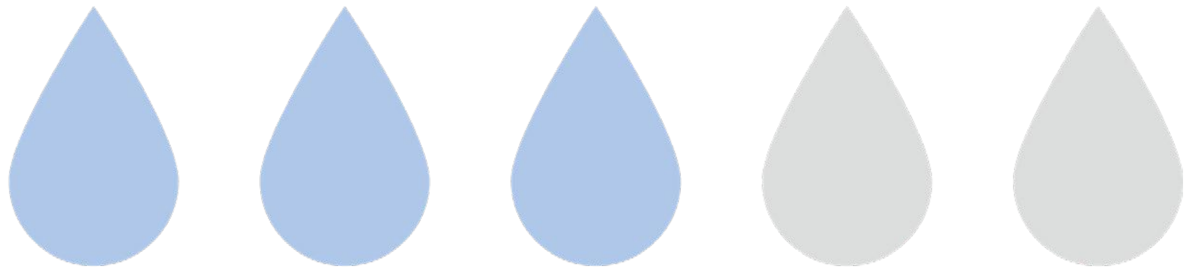
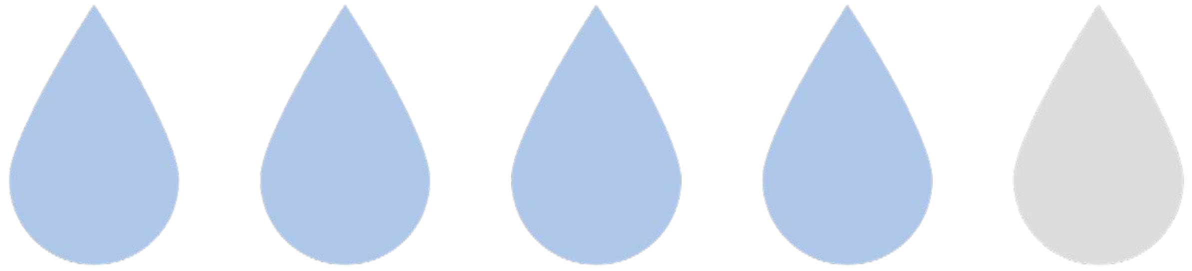
Reactive dyes	Widely used in textiles with excellent fastness
Disperse dyes	Mainly used for synthetic fibers, with continuous growth.
Vat dyes	Common in denim production, driven by eco-friendly trends.
Acid dyes	Applied to wool and silk, with increasing interest in sustainable options.
Direct dyes	Used in paper and leather industries.
Others	Includes fluorescent dyes.

Table 4 shows reactive, disperse, and direct dyes lead the market; reactive dyes alone take 35%, pointing to key areas for sustainable alternatives.

Water Usage Summary

• Comparative Water Consumption Across Dye Section

The following water usage comparison summarises the four dye groups explored in this project (Indigo, Madder, Reactive Blue 19, and Reactive Red 195). Their detailed classification (natural, synthetic, bio-based), properties, and regulatory context are introduced in the subsequent pages.

Indigo (industrial)	Low–moderate water intensity (industry benchmark ca. 3–4 L/kg yarn for rope/slasher processes). Efficient machinery and recycling reduce water use.	
Indigo (craft / vat)	Moderate water intensity. Fermentation vats and repeated dips/ rinses require ongoing water management; sediment/wash steps raise consumption.	
Madder (plant root)	Moderate–high water intensity. Boiling, filtering and multiple rinses increase water demand; pre-treatments add further water.	
Reactive dyes (RB19 / RR195)	Moderate–high to high water intensity. Post-treatment washing (soap wash, rinses) often drives up total water use.	

Sustainability Standards and Dye Regulation

- These standards provide the foundation for the evaluation indicators used in the Traffic Light System

	Standard	Scope	Key Focus	Relevance to Project
	GOTS	Global	Water Biodegradability Toxicity	Low impact natural dyeing
	OEKO-TEX 100	Global	Safety Human health	Testing and fastness compliance
	REACH	EU	Registration Evaluation Authorization Restriction of chemicals	Chemical restriction for synthetics
	Testex	Europe	Environmental protection textile certification	Certification link to OEKO-TEX

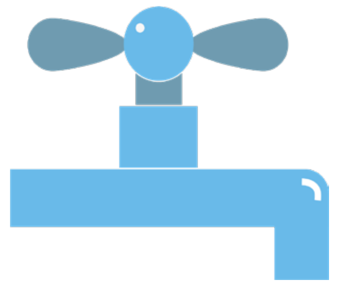
Figure 7. Data: GOTS logo, OEKO-TEX logo, REACH logo, TESTEX logo, accessed 15 Nov 2025.

Textile dyeing is regulated under multiple sustainability standards to ensure water safety, chemical control, and consumer health. These frameworks guide designers and brands in selecting compliant and safer materials.

(GOTS, 2020): water & toxicity & biodegradability

- Require reduction of energy and water use per kg of textile output.

Water consumption



- Discharge COD < 30 ppm; used for water impact evaluation.

Water treatment

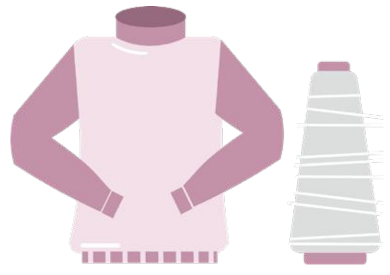
- Auxiliaries must achieve ≥70% or ≥95% biodegradability.

Biodegradability

- Prohibit toxic chemicals such as heavy metals, carcinogenic azo dyes.

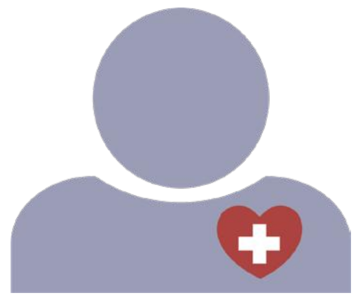
Toxicity

(OEKO-TEX, 2021): human health impact & colorfastness



- Finished textiles must meet pH 4.0–7.5, no abnormal odor, color fastness ≥3–4.

Safety of finished textiles



- Test for formaldehyde, heavy metals, pesticide residues, PAHs, etc. to ensure safety.

Human health impact

- Restrict allergenic or carcinogenic dyes (e.g., aniline, Michler's ketone, aromatic amines).

Control of allergens and carcinogens

Figure 8-14 . Icons designed by author.

OEKO-TEX Human Health Impact

- How OEKO-TEX® safety criteria inform my dye testing methods

OEKO-TEX® Requirement	Relevance to My Project
pH 4.0–7.5 for skin-contact textiles	Supports my pH-variation tests (acid/alkaline bath).
Restrictions on carcinogenic amines	Informs synthetic dye toxicity evaluation.
Limits on heavy metals (Cr, Pb, Cd, Hg)	Justifies excluding chromium mordants; supports tannin-based mordants.
Odor & colorfastness requirement	Links to my wash/light/rub fastness tests.

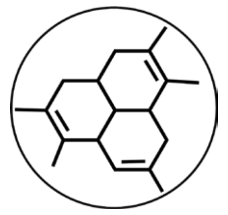
	• pH & Skin Safety OEKO-TEX requires neutral–slightly acidic textiles; this validates my pH-shift dye tests.
	• Heavy Metal Avoidance The standard restricts chromium/lead, supporting my use of natural tannin mordants.
	• Allergen & Carcinogen Control Links directly to the evaluation of synthetic dyes (e.g., reactive dye residues).
	• Fastness & Consumer Safety Colorfastness ≥3–4 aligns with my wash/light/rub test scoring.

Figure 15-17 . Icons designed by author.

Linking standard to practice: OEKO-TEX limits on skin-contact pH, carcinogenic amines and heavy metals inform our mordant selection. To reduce heavy-metal residues and related health risks, gallnut and tea-tannin were used as natural mordants/pre-treatments. Experimental evidence supporting this choice is shown on the “Gallnut / Tannin” page.

Typologies of Dyeing System

- Understanding three parallel pathways: natural dyes, synthetic dyes, and emerging bio-based colour systems.

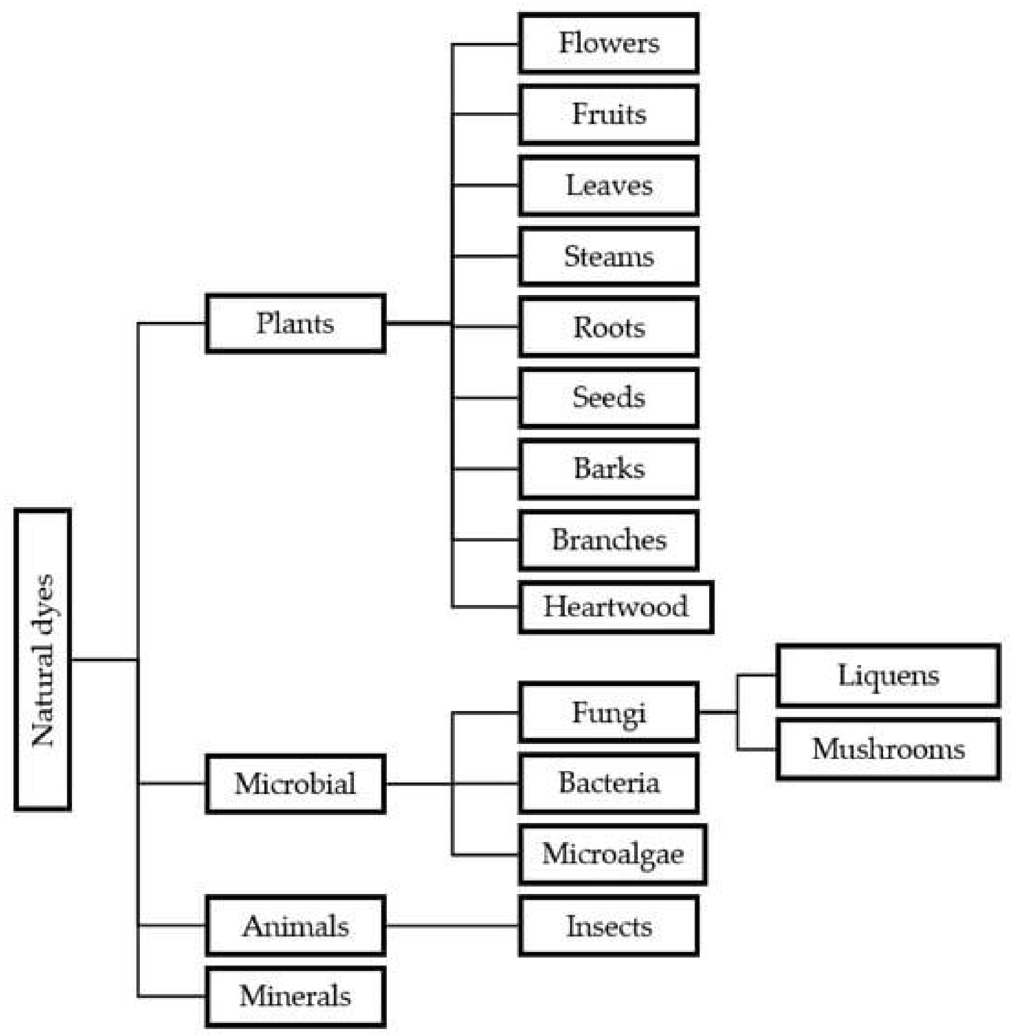


Figure 3. Data: Sustainability (MDPI), accessed 15 Nov 2025.

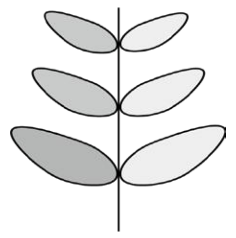
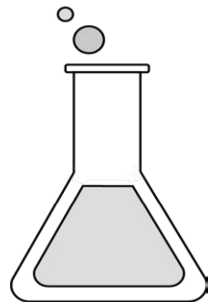
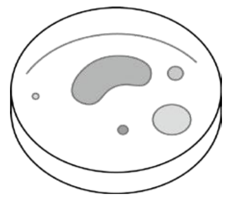
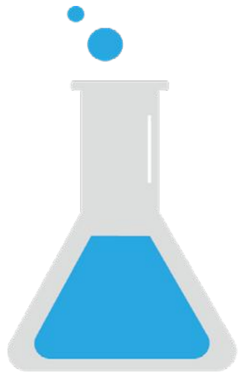
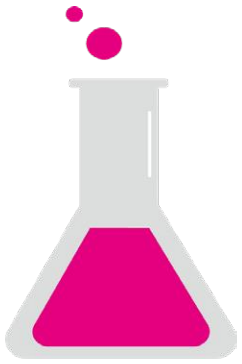
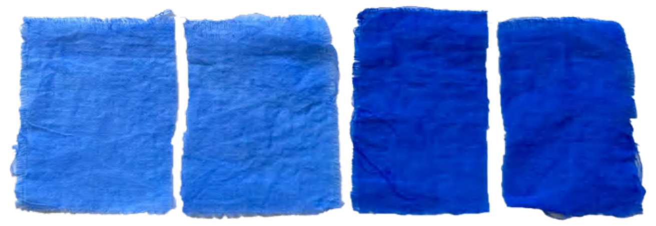
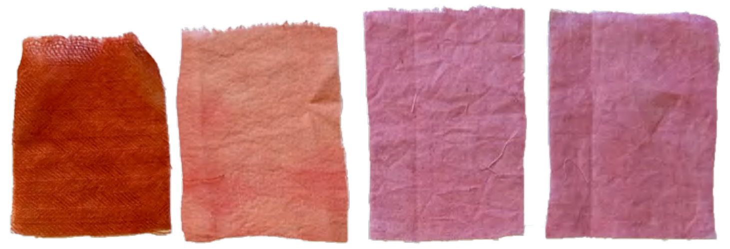
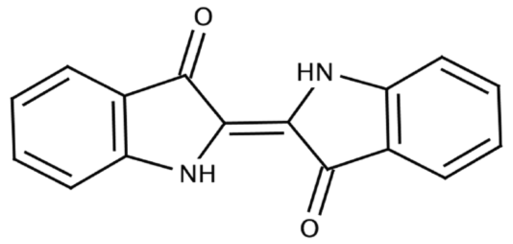
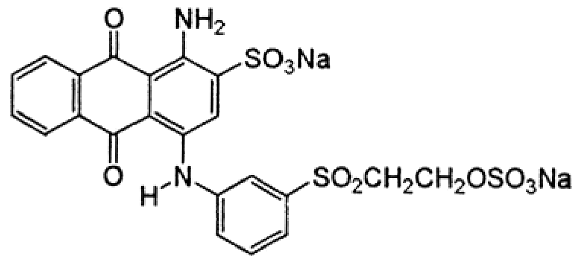
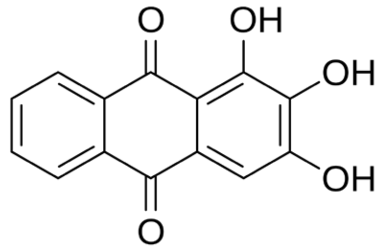
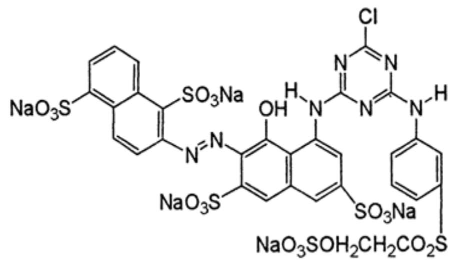
	Natural Dyes	• Plant-based sources (indigo, madder) • Variable colour control; craft expertise required • Locally rooted cultural production
	Synthetic Dyes	• Reactive dyes (e.g., Reactive Blue 19, Reactive Red 195) • Highly scalable with predictable colour • Environmental burden linked to wastewater chemistry
	Bio-based Dyes	• Produced via microbial fermentation (e.g., Streptomyces pigments, bacterial indigo, fungi-based melanin) • Lower land use; early-stage production • Limited colour range; stability still developing

Figure 4-6. Icons designed by author.

This project centres on natural and reactive dyes as the core experimental systems. Bio-based colouration is positioned as an extension category — an emerging third pathway referenced to contextualise future sustainable dye systems, rather than forming part of the main experimental work.

Dye Selection

Based on sustainability indicators (toxicity, biodegradability, colour fastness, water use, scalability) I selected five representative dye groups for comparison.

Indigo (Natural, Guizhou & Bio-indigo powder)	Reactive Blue 19 (Synthetic, benchmark for Indigo)	Madder (Natural, China & India)	Reactive Red 195 (Synthetic, benchmark for Madder)
 Figure 18-21. Icons designed by author.			
 Figure 22-25. Dye samples photographed by author.			
Specific • Strobilanthes (South Asia, Southeast Asia and the area around Queensland) • Indigofera tinctoria (China, India)	Extensively used in maor textile-producing countries such asChina, India, Bangladesh, Vietnam, and Turkey.	Specific • Rubia tinctorum (Europe, western Asia and Africa) • Rubia cordifolia (Asia, Europe and Africa)	Mass production globally, with China, India, and Turkey being the major manufacturing and usage countries.
Main pigment components • $C_{16}H_{10}N_2O_2$  Figure 26. Indigo chemical structure. Data: MedChemExpress, accessed 15 Nov 2025.	Main pigment components • $C_{22}H_{16}N_2NA_2O_{11}S_3$  Figure 27. Reactive Blue 19 chemical structure. Data: World Dye Variety, accessed 15 Nov 2025.	Main pigment components • Alizarin ($C_{14}H_8O_4$)  Figure 28. Alizarin (madder) chemical structure. Data: MedChemExpress, accessed 15 Nov 2025.	Main pigment components • $C_{31}H_{19}ClN_7NA_5O_{19}S_6$  Figure 29. Reactive Red 195 chemical structure. Data: World Dye Variety, accessed 15 Nov 2025.

Dye Case Studies

• Indigo – Traditional Practice

Case 1 :
Paimo Village Indigo Workshop, Gui Zhou

1


Washing area


Dyeing area


Batik Corridor


Wax Painting

Figure 30-33. Paimo Village Indigo Workshop, Guizhou. Photograph by author.

The Paimo Indigo Workshop integrates dyeing, batik, and local tourism, showing how traditional craft systems can form sustainable networks outside industrial frameworks.

Case 2 :
Indigo Interview with Zhang Shixiu, local indigo practitioner

2


Figure 34. Indigo interview with Zhang Shixiu, local indigo practitioner in Paimo Village. Photograph by author.

Q1: What plant is used for this indigo vat? Is it locally grown in the village?
A1: It's made from Strobilanthes cusia, which is grown locally.
This ensures traceability and reduces outside dependence.

Q2: How often is the vat replaced, and how much fabric can it dye?
A2: It's replaced only when no longer usable, with the whole vat changed at once.
This highlights resource circularity and extended use.

Q3: Does the village still cultivate indigo plants, or are they sourced elsewhere?
A3: They're harvested twice a year (summer and autumn), leaving stems to regrow.
This supports renewable and sustainable supply.

Q4: In Paimao Village, how much indigo can one vat produce per season, and how much fabric can it dye?
A4: About five jin (≈2.5 kg) of indigo plants can produce one jin (≈0.5 kg) of indigo paste, grown in an area of around 3 square meters.

Note: Field observations revealed low scalability in traditional indigo production due to seasonal harvesting, vat limitations, and manual expertise.
Reflection: Discussed natural material sourcing, fermentation control, and ways to sustain traditional dyeing practices in a modern context.

Dye Case Studies

• Indigo – Traditional Practice

Short description of local process

Figure 35-40. Indigo dyeing process, Paimo Village Indigo Workshop. Photograph by author.

The workshop combines batik and indigo dyeing as a full traditional craft chain.

The gradient test visualizes how exposure duration affects oxidation and color depth, offering insight for sustainable indigo control.

Indigo Dyeing Time Gradient

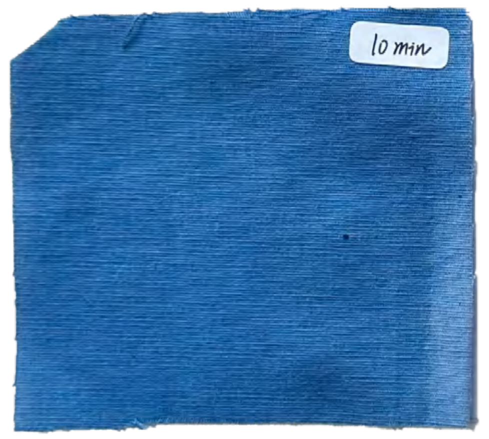
Observation result:
5min/10min: Presents a light bluishgreen color.
60 minutes: The blue color gradually deepens.
6h+ : Close to deep blue or even indigo black.

Process recipe

cotton

05min

10min



60min

06hour

Figure 41. Indigo dyeing process, Paimo Village Indigo Workshop. Images and collage by author.

Dye Case Studies

- Indigo – Lab/Home Experiments

Dye bath formula: 3.25g indigo powder + 10g soda ash +25g reducer + 2.5L hot water.

Figure 42. Home-lab indigo powder dyeing process. Photograph by author.

Process recipe

wool silk linen cotton

01min

05min

15min

60min

Observation: The longer the dyeing time, the deeper the color.

Figure 43. Home-lab indigo powder dyeing process. Images and collage by author.

Comparison: Traditional vs Bio Indigo

- Table: source / process environment / sustainability/ colour control

Aspect	Traditional Indigo (Guizhou)	Bio indigo powder (Home/ Lab)
Source	Plant Strobilanthes cusia	Synthetic biology, microbes
Process environment	Village fermentation vat	Controlled lab/home vat
Sustainability	Local renewable resource	Saves farmland, continuous bio-production
Affinity to fabric	Excellent adhesion on cotton and linen	The fabric colour is uniform.
Colour control	Based on artisan experience	Adjustable by time/oxidation

Summary note: (includes scalability)

Traditional indigo offers cultural craft value but shows seasonal limits and vat variability. Bio-indigo provides consistent colour and better scalability, explaining their different “colour control” and “scalability” scores in the Traffic-Light evaluation.

Madder – Fabric & Pre-treatment Setup

Note: This page provides experimental evidence supporting the OEKO-TEX-driven decision to avoid heavy-metal mordants.

- **Pre-treatment** (Preparation → Mordant → Dyeing → Variable)

These pre-treatments (tannins, pH, iron, extraction) directly respond to the sustainability indicators identified in the previous page — particularly pH suitability, toxicity control, and colorfastness improvement.

Section A: Fabric Selection and pre-wash

- Purpose: Ensure consistent absorbency and remove surfactants before comparing dye behaviours.

- Cotton/linen/Wool/silk

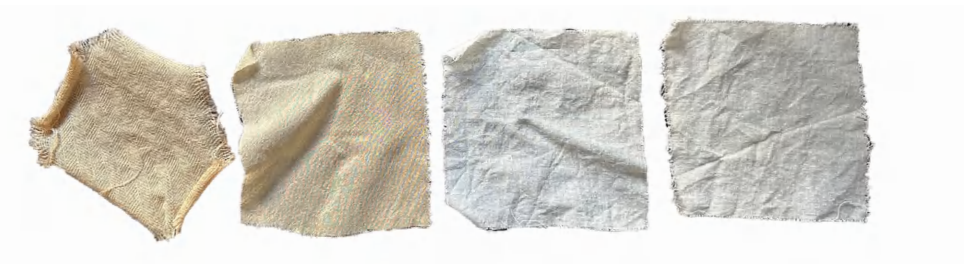
- All fabrics were pre-washed in neutral detergent (10 min) to remove sizing and impurities before grouping

- Color fixation treatment: All sample fabrics > Soak inalum solution for 1 hour.

Section B: Mordanting Groups

- Fabrics divided into three pretreatment groups with different mordants before dyeing.
- Tannin: Natural tannin mordanting enhances colour durability and reduces fading.
- Why mordants were used:
  Mordants alter dye–fiber bonding and are directly related to fastness and chemical safety indicators highlighted in OEKO-TEX and GOTS.

1. Untreated (no tannin) → Baseline reference
2. Tea tannin (steeped in black tea) → Natural, low-toxicity mordants improving wash fastness.

3. Gallnut tannin (steeped in gallnut) → Natural, low-toxicity mordants improving wash fastness.


4. Iron mordant → Demonstrates how ferrous ions shift hue and reduce light fastness.


Section C: Dye Material Preparation

- Purpose: Hydration activates dye molecules and ensures uniform extraction.

- Madder roots were soaked in water and vinegar for at least 24 hours, with the water replaced every 8 hours.
- This process softens the roots and activates the dye molecules before boiling.



Section D: pH Variation

- Purpose: OEKO-TEX requires pH suitability (4.0–7.5). Testing acidic and alkaline environments reveals dye sensitivity and informs industry applicability.

- pH-adjusted dye baths were compared to observe color shift from orange to pink hues.
- Shows the sensitivity of madder dye to acidic or neutral conditions.

pH < 7


pH > 7


Figures 44-47. Chinese Madder dye pre-treatment workflow, including fabric pre-wash, tannin mordanting, madder root hydration, and pH variation tests. All photographs by author.

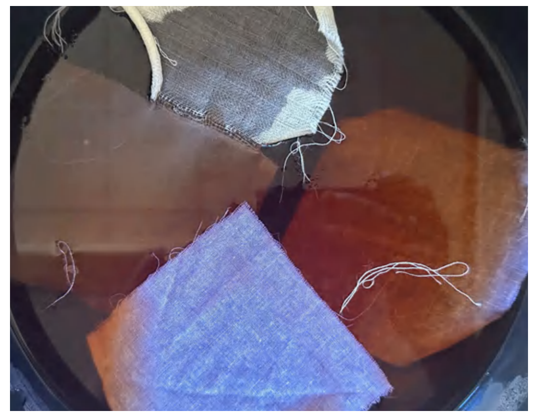
Madder – Chinese (Rubia cordifolia)

- Madder – Lab/Home Experiments

Process: Boiling and dyeing.

Figure 48. Chinese Madder dyeing process. Photograph by author.

Source regions : (Gansu/ Xinjiang/ Qinghai)



Untreated groups

01

Gallnut groups

02

Tea groups

03

Mordant with iron

04

Observation: Tannin groups achieved a deeper dyeing effect.

Figure 49. Home-lab madder dyeing process collage (Chinese madder). Images and collage by author.

Madder – Fabric & Pre-treatment Setup

Note: This page provides experimental evidence supporting the OEKO-TEX-driven decision to avoid heavy-metal mordants.

- Pre-treatment (Preparation → Mordant → Dyeing → Variable)

These pre-treatments (tannins, pH, iron, extraction) directly respond to the sustainability indicators identified in the previous page — particularly pH suitability, toxicity control, and colorfastness improvement.

Section A： Fabric Selection and pre-wash

- Purpose: Ensure consistent absorbency and remove surfactants before comparing dye behaviours.

- Cotton/linen/Wool/silk

- All fabrics were pre-washed in neutral detergent (10 min) to remove sizing and impurities before grouping

- Color fixation treatment: All sample fabrics > Soak inalum solution for 1 hour.

Section B: Mordanting Groups

- Fabrics divided into three pretreatment groups with different mordants before dyeing.

- Tannin: Natural tannin mordanting enhances colour durability and reduces fading.

- Why mordants were used:
Mordants alter dye–fiber bonding and are directly related to fastness and chemical safety indicators highlighted in OEKO-TEX and GOTS.

1. Untreated (no tannin) → Baseline reference

2. Tea tannin (steeped in black tea) → Natural, low-toxicity mordants improving wash fastness.

3. Gallnut tannin (steeped in gallnut) → Natural, low-toxicity mordants improving wash fastness.

4. 3 days redye groups → Test if the dye bath still works after 3 days.

Color became lighter and less even
→ dye bath is reusable, but not stable
for consistent production.

Section C: Dye Material Preparation

- Purpose: Hydration activates dye molecules and ensures uniform extraction.

- Madder roots were soaked in water for at least 2 hours.
- This process softens the roots and activates the dye molecules before boiling.

Section D: pH Variation

- Purpose: OEKO-TEX requires pH suitability (4.0–7.5). Testing acidic and alkaline environments reveals dye sensitivity and informs industry applicability.

- pH-adjusted dye baths were compared to observe color shift from orange to pink hues.
- Shows the sensitivity of madder dye to acidic or neutral conditions.

Figures 50-53. India Madder dye pre-treatment workflow, including fabric pre-wash, tannin mordanting, madder root hydration, and pH variation tests. All photographs by author.

Madder – Indian (Rubia tinctorum)

• Madder – Lab/Home Experiments

Process: Boiling and dyeing.

Figure 54. Indian Madder dyeing process. Photograph by author.

Source regions : India

Untreated groups

01

Gallnut groups

02

Tea groups

03

3-day redye groups

04

Observation: Tannin groups achieved a deeper dyeing effect.

Figure 55. Home-lab madder dyeing process collage (Indian madder). Images and collage by author.

Comparison: Chinese vs Indian Madder

- Table: source / process environment / sustainability/ colour control

Aspect	Chinese Madder (Rubia cordifolia)	Indian Madder (Rubia tinctorum)
Source	Gansu / Xinjiang / Qinghai (Asia origin)	India / West Asia / Europe
Process environment	Home dye pot, traditional extraction	Controlled lab/home vat
Sustainability	Local renewable resource	Saves farmland, continuous bio-production
Affinity to fabric	pH-sensitive, tends to shift between red–brown	More stable hue, orange-red tone consistent
Colour control	Strong on silk, uneven on cotton	Even coverage on both silk and cotton

Summary note: (includes scalability)

Chinese madder gives warm but less reproducible tones, while Indian madder delivers stronger, more stable colour across fibres. Their performance differences reflect variation in “process stability”, “colour control”, and “scalability” in the Traffic-Light system.

Reactive Dye RB19

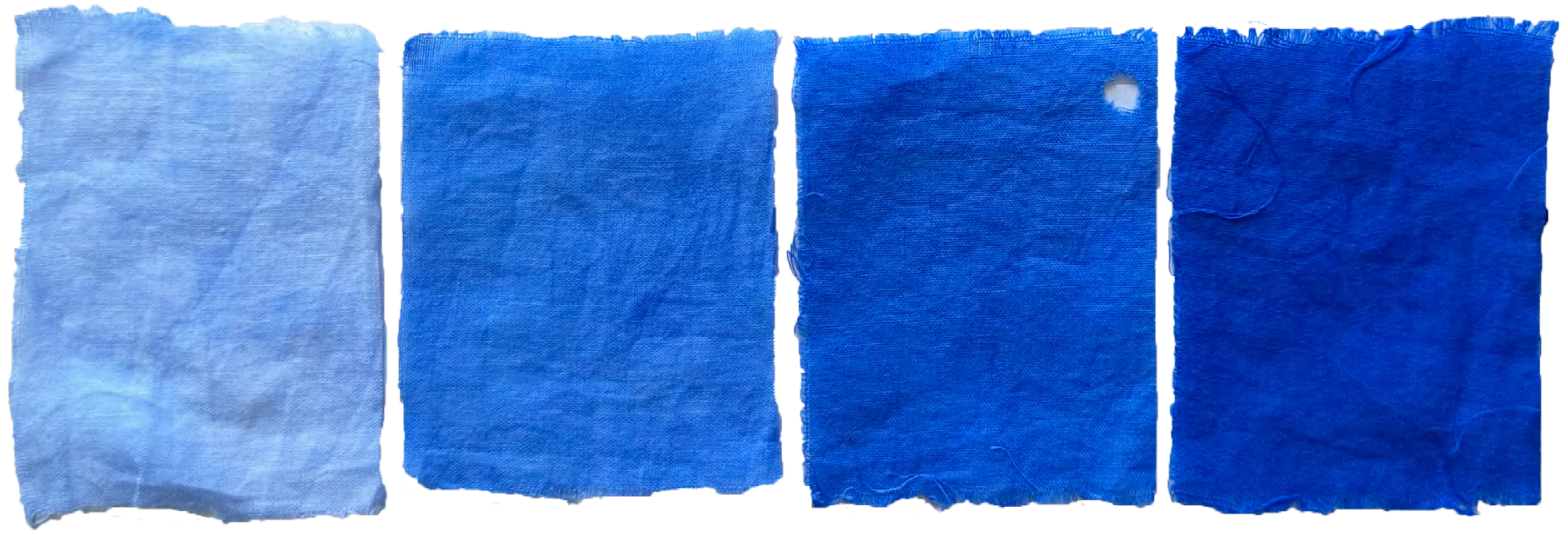
- Cotton samples (5/15/30/60min)
- Process recipe (salt + alkali, bath ratio)

General dyeing procedure (cotton; lab-scale, household version)

Figure 56. Fabric Pre-treatment. Photograph by author.

Process: Boiling and dyeing.

Figures 57. Reactive Blue 19 dyeing process collage. Images and collage by author.



5min 15min 30min 60min

Observation: The longer the dyeing time, the deeper the color.

Figure 58. Reactive Blue 19 dyeing process. Photograph by author.

1. Wash fabric in 40-50 °c water with mild detergent (10-15min); rinse and keep moist.

2. Set bath ratio 1:20, add salt (4.8 g), then dye (2% owf, pre-dissolved).

3. Maintain 50-60 'c; after 10 min add soda ash (1.8 g/L) slowly, continue to time points (5/15/30/60 min).

4. Rinse in running water>soap wash (60°C, 10-15 min, 2 g/L detergent) > rinse and air dry.

Reactive Dye RR195

- Cotton samples (5/15/30/60min)
- Same process, note on differences

General dyeing procedure (cotton; lab-scale, household version)

Figure 59. Fabric Pre-treatment. Photograph by author.

Process: Boiling and dyeing.

Figure 60. Reactive Red 195 dyeing process collage. Images and collage by author.

5min 15min 30min 60min

Observation: The longer the dyeing time, the deeper the color.

Figure 61. Reactive Red 195 dyeing process. Photograph by author.

1. Wash fabric in 40-50 °c water with mild detergent (10-15min);
rinse and keep moist.
2. Set bath ratio 1:20, add salt (4.8 g), then dye (2% owf, pre-dissolved).
3. Maintain 50-60 'c; after 10 min add soda ash (1.8 g/L) slowly, continue to time points (5/15/30/60 min).
4. Rinse in running water>soap wash (60°C,10-15 min, 2 g/L detergent) > rinse and air dry.

Comparison: Natural vs Synthetic

- Table: source / process environment / sustainability/ colour control

Aspect	Natural dyeing (Indigo, Madder)	Synthetic dyeing (RB19, RR195)
Source	Plants, roots, biological origin	Petrochemical / synthetic compounds
Process environment	Manual dyeing, pH and time dependent	Industrial precision, controlled recipes
Sustainability	Renewable but resource-intensive (water, mordant)	Efficient but may produce toxic effluents
Affinity to fabric	Variable by fibre type, better on natural fibres	Consistent, strong fixation on multiple fibres
Colour control	Sensitive to conditions, unique variations	Highly reproducible and stable

Summary note: (includes scalability)

Natural dyes are biodegradable but variable and process-intensive; reactive synthetic dyes are highly consistent and scalable but chemically heavier. These contrasts define their differing “environmental impact”, “colour control”, and “scalability” scores in the Traffic-Light assessment.

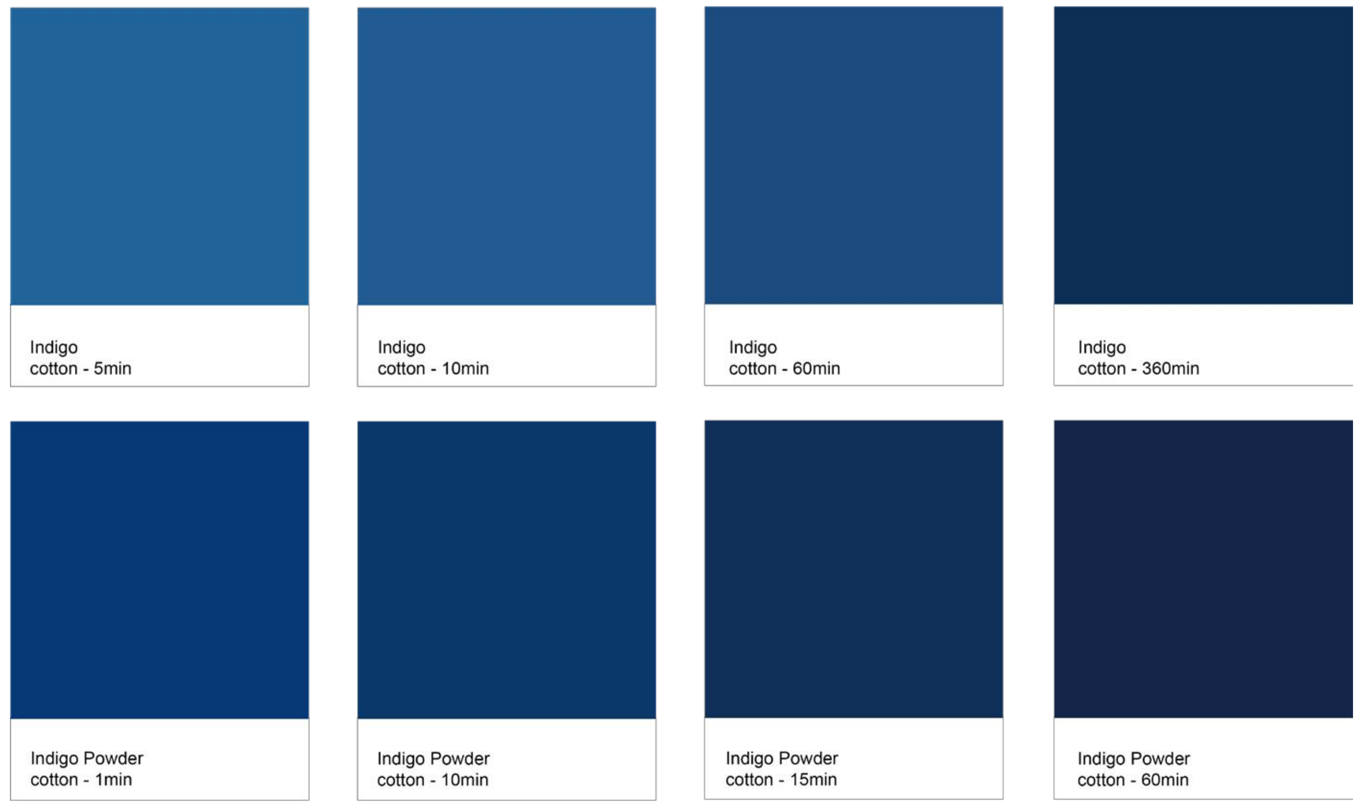
Colour Atlas of Dye Experiments

- A unified colour atlas comparing dye behaviours across fibres, durations, and dye systems.

India (Rubia tinctorum) + Silk fabric and Cotton fabric

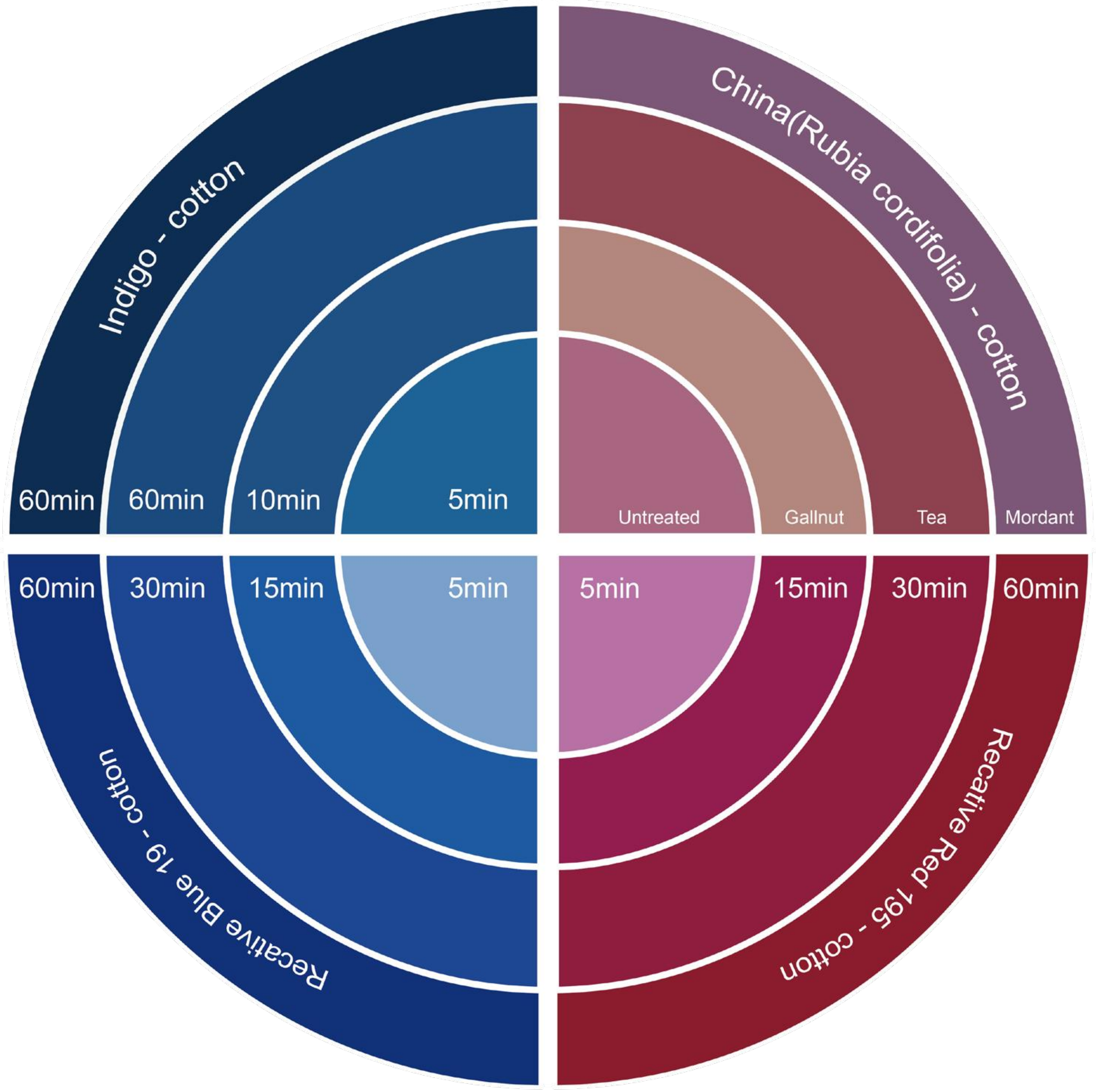
India (Rubia tinctorum) + Silk fabric and Cotton fabric

Indigo and Indigo Powder + Cotton fabric



Reactive Blue 19 and Reactive Red 195 + Cotton fabric

Figures 61 – 65. Colour card. Designed by author.

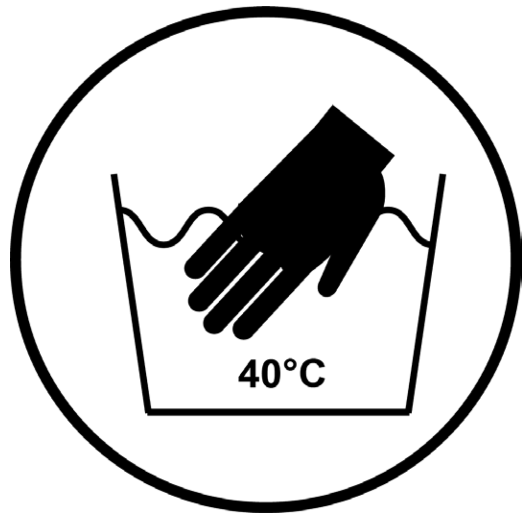


Radial mapping shows how colour deepens or shifts with different dye times and treatments.

Testing & Evaluation

- Testing Methods: wash / rubbing / light / perspiration

All tests were evaluated using ISO grey scale (1–5), ensuring comparability between natural and reactive dyes.

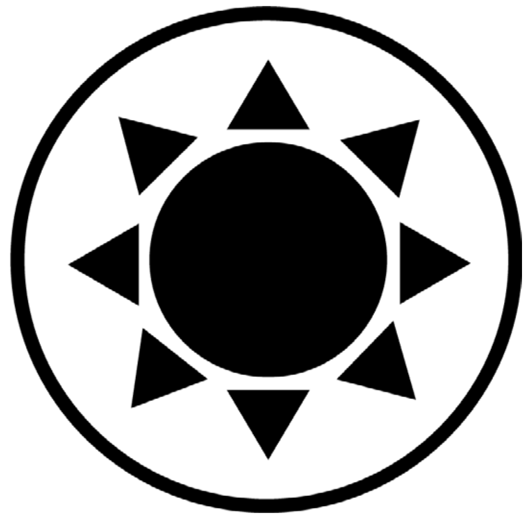


1. Wash fastness

40 °C warm wash, neutral detergent, 10 min gentle stirring, rinse twice, air dry.
→ Rate colour change (1–5)

2. Dry/Wet rubbing fastness

Dry & wet rubbing (10 strokes each) with white cotton cloth.
→ Observe staining level (0–5)

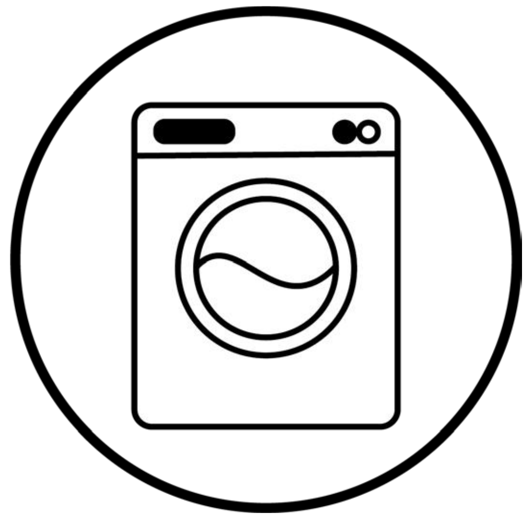


3. Light fastness

Half covered, half exposed for 7 days sunlight or 24h UV exposure.
→ Rate fading (1–5).

4. Perspiration fastness

Acid/alkaline soak (vinegar / soda), press 2 h, dry.
→ Check staining or discolouration.(1–5)



5. Machine Wash Test

40 °C mild cycle, 30 min, mesh bag.
→ Note visible fading or colour transfer.

6. Grey Scale Evaluation

Compare pre/post samples with ISO grey scale.
→ Visual rating reference for all tests.

Figure 62. Testing method icons for wash, rubbing, light, and perspiration. Icons designed by author.

Five household-based tests were conducted — hand wash, rubbing, perspiration, light, and machine wash — followed by grey scale comparison.
These tests assess colour durability and form the basis of the traffic-light evaluation system.

ISO Grey Card & Industry Feedback ISO

- Interview with textile testing friend: “Clients usually require ≥4 grade.”
- Traffic light system (Fastness Evaluation)

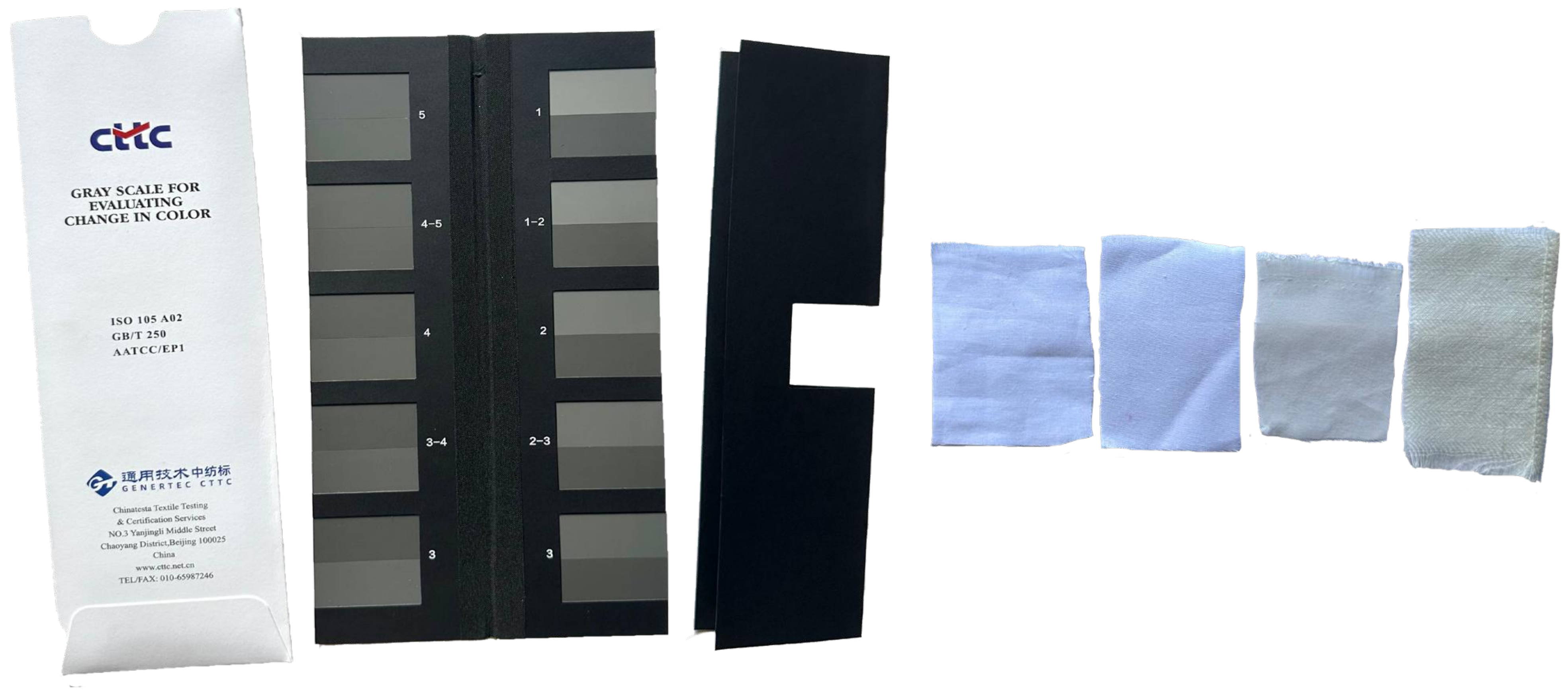


Figure 63. ISO Grey Card set used for color fastness evaluation. Photograph by author.

Industry insight:

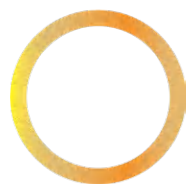
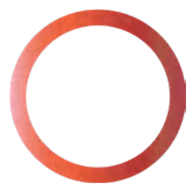
Insights from a professional working in a textile testing company:

1. Clients care most about washing fastness and light fastness especially for export orders.

2. A grade of >4 is generally required; lower results may cause rejection.

3. In practice, grey scale is often the first step; final results are sometimes supported byinstrumental colour measurement (CIELAB ▲E).

4. For natural dyes, a common issue is poor rubbing fastness often below Grade 3.

Color	Label	Meaning
	Excellent/ Recommended	Excellent fastness and low environmental impact.
	Acceptable/ Use with caution	Acceptable results but need controlled conditions.
	Poor/ Not recommended	Poor fastness or unsustainable performance.

Figures 64 – 66. Traffic-light rating icons (green, yellow, red). Icons designed by author.

Traffic light system (Fastness Evaluation)

Fastness results (wash, light, rubbing, perspiration, machine wash) are evaluated using the ISO gray scale.
These ratings are translated into the Traffic-Light System to guide sustainable dye selection.

Results – Wash Fastness

- Hand wash with Indigo Powder

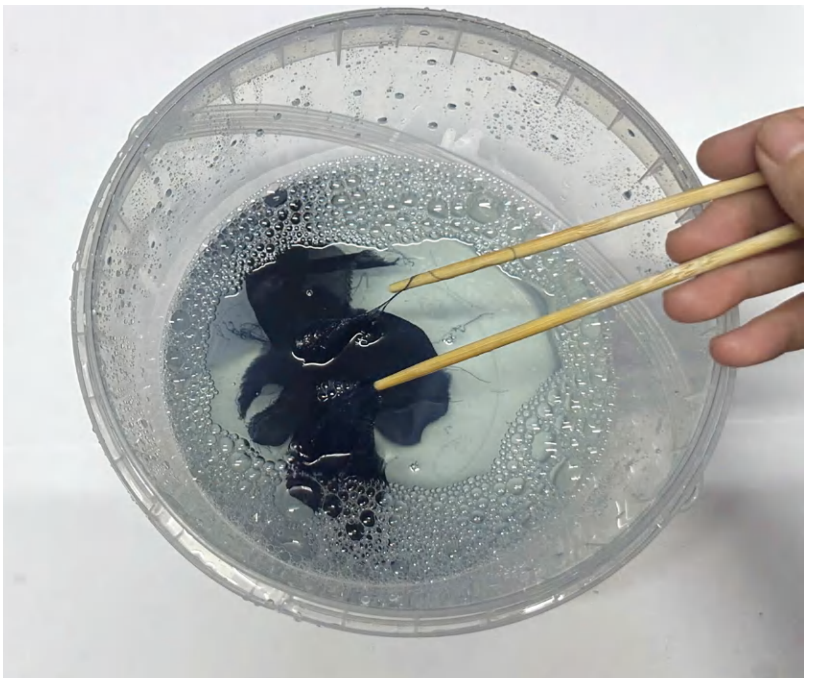
Washing fastness-test color fading & staining on adjacent fabric

1 min Indigo – silk and cotton

60 min Indigo – silk and cotton

Warm water at 40° C and neutral detergent

Gently stir for 10 minutes



Rinse twice with clean water

Figures 67 – 72. Indigo wash-fastness test, including ISO Grey Scale comparison (before/after wash) and full experimental workflow. All photographs by author.

Observation: There was little to no difference between the washed and unwashed fabrics.

Bullet point: Indigo | 3–4 | Slight fading with acceptable performance |

Results – Wash Fastness

- Hand wash with Chinese Madder

Figures 73 – 78. China Madder wash-fastness test, including ISO Grey Scale comparison (before/after wash) and full experimental workflow. All photographs by author.

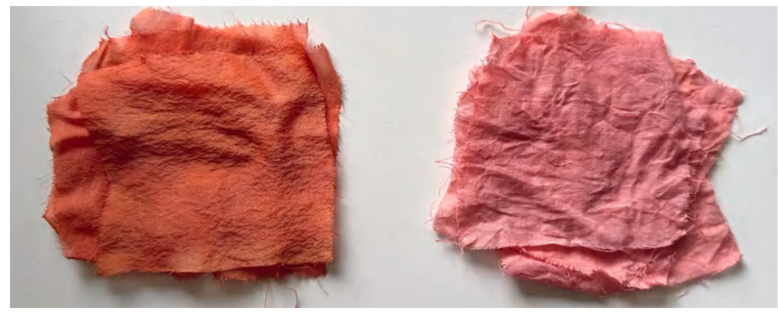
Observation: The untreated fabric faded slightly after washing, but the Tannin (gallnut) fabric remained nearly the same.

Bullet point: Madder | 3–4 | Slight fading with acceptable performance |

Washing fastness-test color fading & staining on adjacent fabric

Madder – silk and cotton

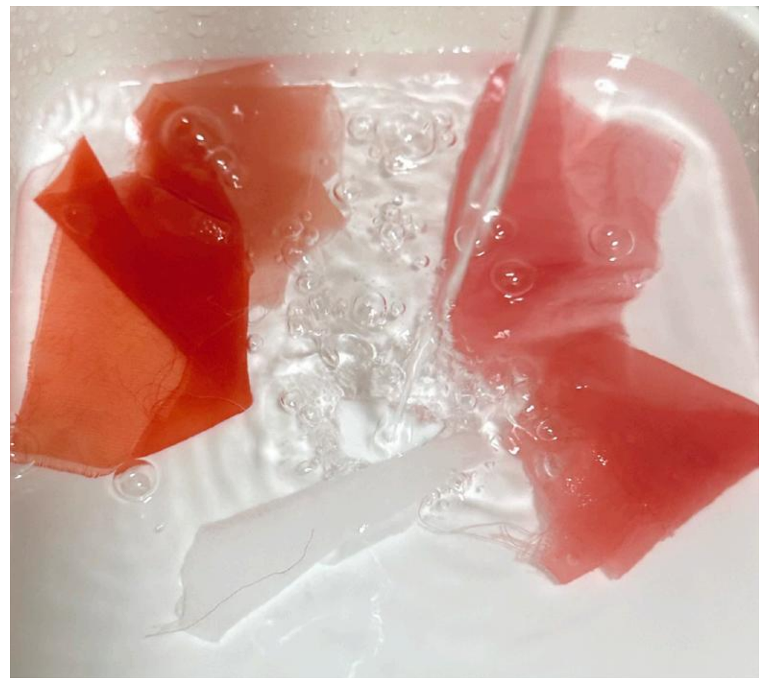
Madder with gallnut – silk and cotton



Warm water at 40° C and neutral detergent

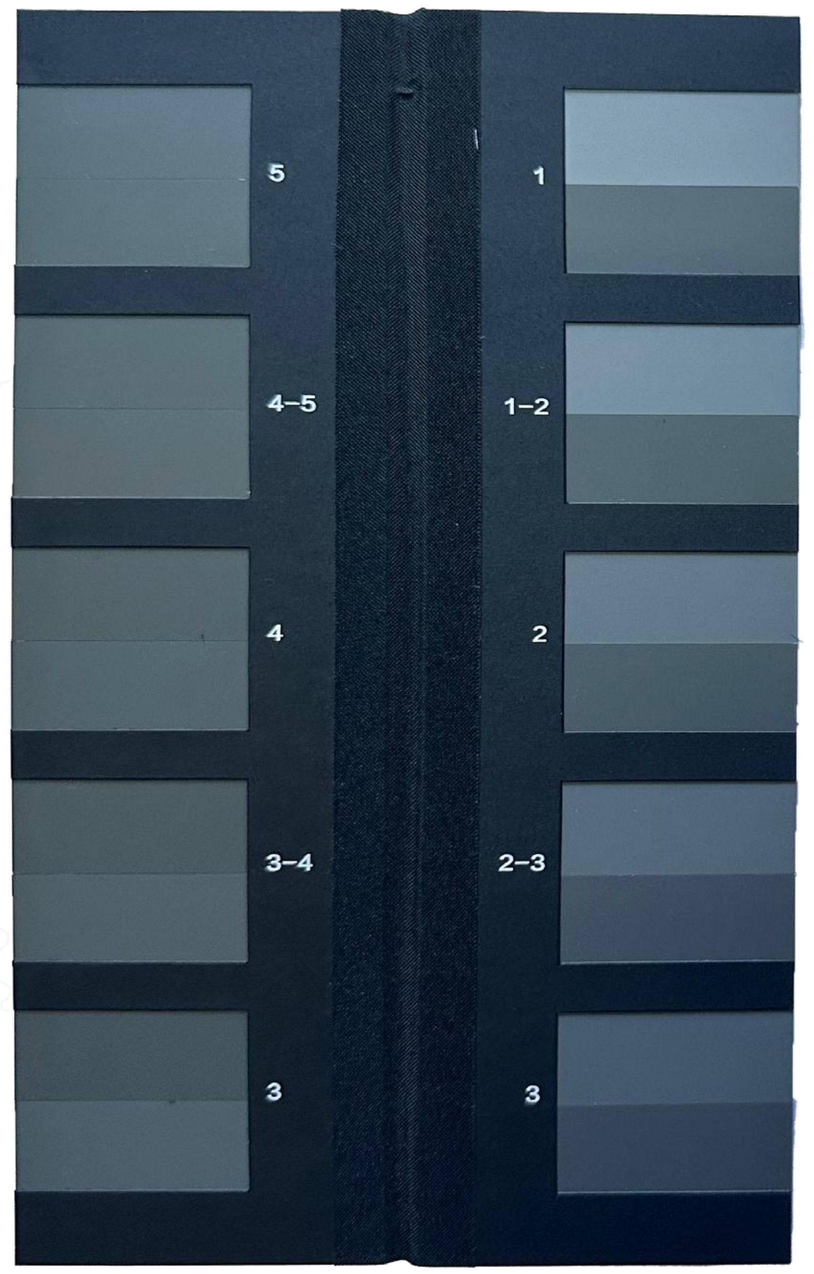
Gently stir for 10 minutes

Rinse twice with clean water



Results – Wash Fastness

- Hand wash with Indian Madder



Figures 79 – 84. India Madder wash-fastness test, including ISO Grey Scale comparison (before/after wash) and full experimental workflow. All photographs by author.

Observation: The untreated fabric faded slightly after washing, but the Tannin (gallnut) fabric remained nearly the same.

Bullet point: Madder | 3–4 | Slight fading with acceptable performance |

Washing fastness-test color fading & staining on adjacent fabric

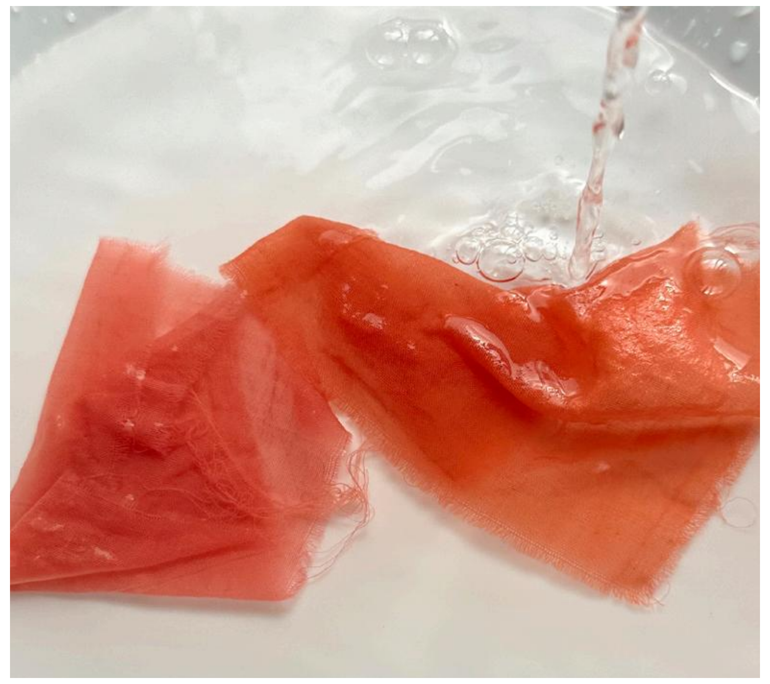
Madder – cotton

Madder with gallnut – cotton

Warm water at 40° C and neutral detergent

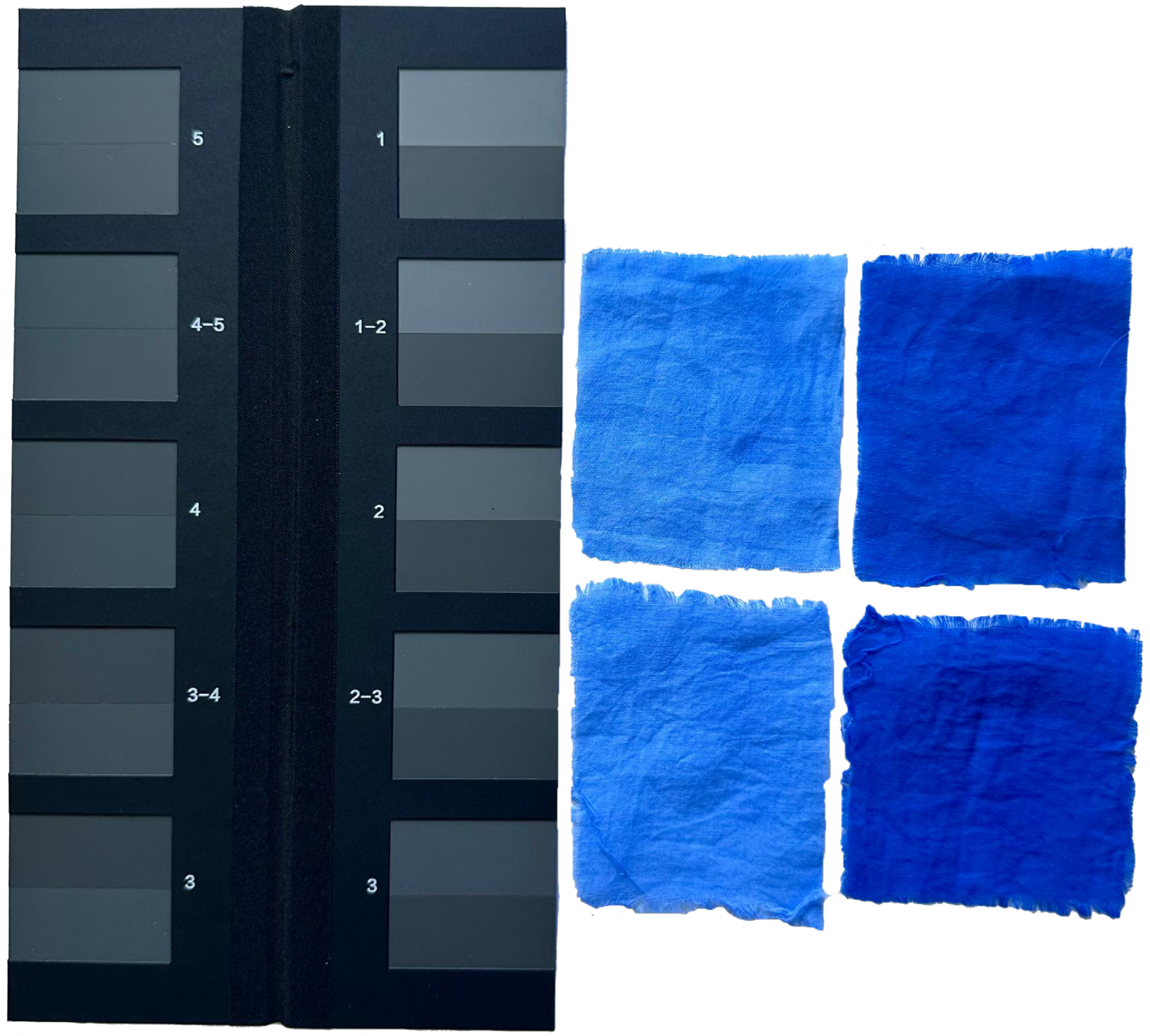
Gently stir for 10 minutes

Rinse twice with clean water



Results – Wash Fastness

- Hand wash with RB19



Figures 85 – 90. RB19 wash-fastness test, including ISO Grey Scale comparison (before/after wash) and full experimental workflow. All photographs by author.

Observation: The Reactive Blue 19 fabric remained almost unchanged after washing.

Bullet point: | RB19 | 4–5 | Excellent stability with no visible fading |

Washing fastness-test color fading & staining on adjacent fabric

15min RB19 – cotton

60min RB19 – cotton

Warm water at 40° C and neutral detergent

Gently stir for 10 minutes

Rinse twice with clean water

Results – Wash Fastness

- Hand wash with RR195

Figures 91 – 96. RR195 wash-fastness test, including ISO Grey Scale comparison (before/after wash) and full experimental workflow. All photographs by author.

Observation: The Reactive Red 195 fabric remained almost unchanged after washing.

Bullet point: | RR195 | 4–5 | Excellent stability with no visible fading |

Washing fastness-test color fading & staining on adjacent fabric

15min RR195 – cotton

60min RR195 – cotton

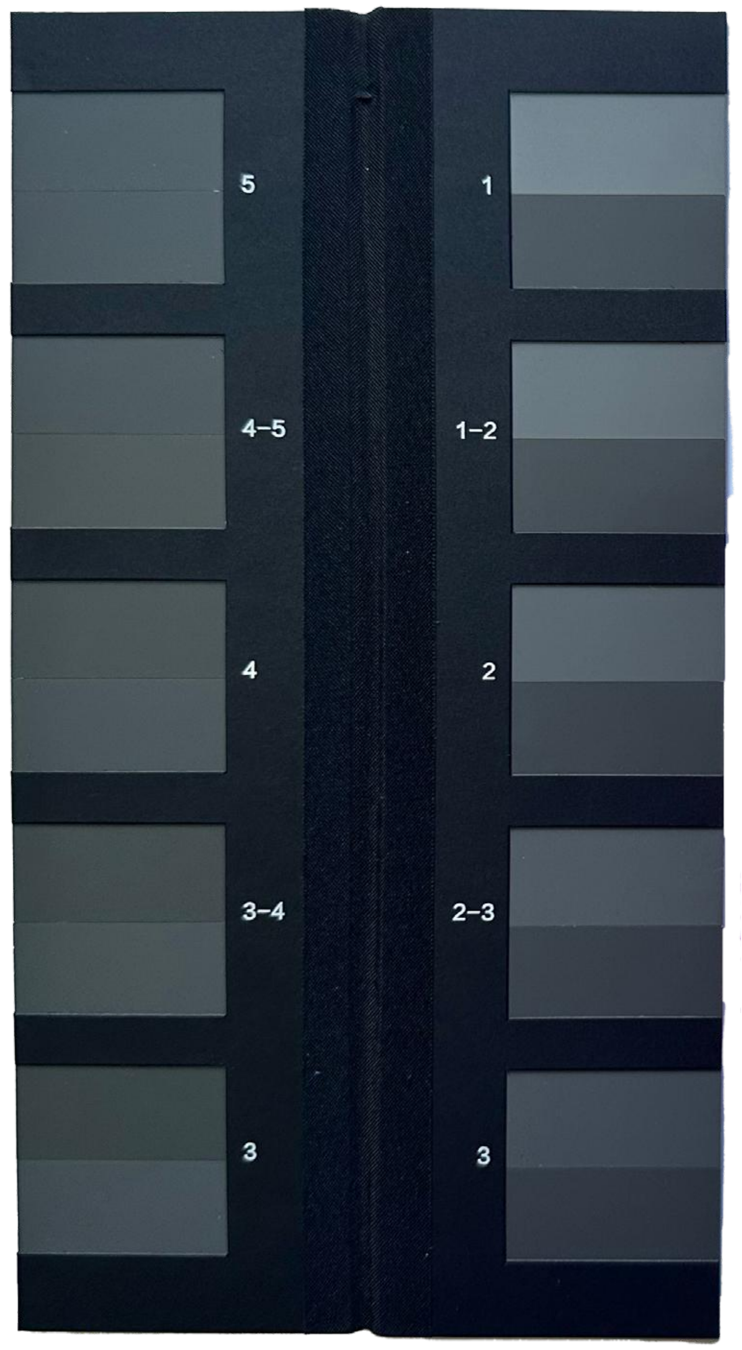
Warm water at 40° C and neutral detergent

Gently stir for 10 minutes

Rinse twice with clean water

Results – Wash Fastness

- Machine wash with Madder/ Indigo Powder/ RB19/ RR195



Figures 97 – 101. Machine wash-fastness result. Photograph by author.

Bullet point: | RR195/RB19 | 4 | Excellent stability with slight fading |
Indigo	3-4	Slight fading with acceptable performance
Chinese madder	2-3	Hue shifted from light pink to light orange
Indian madder	3-4	Slight fading with acceptable performance

Washing fastness-test color fading & staining on adjacent fabric

Place dyed fabrics into mesh washing bags

Add 20 mL neutral detergen

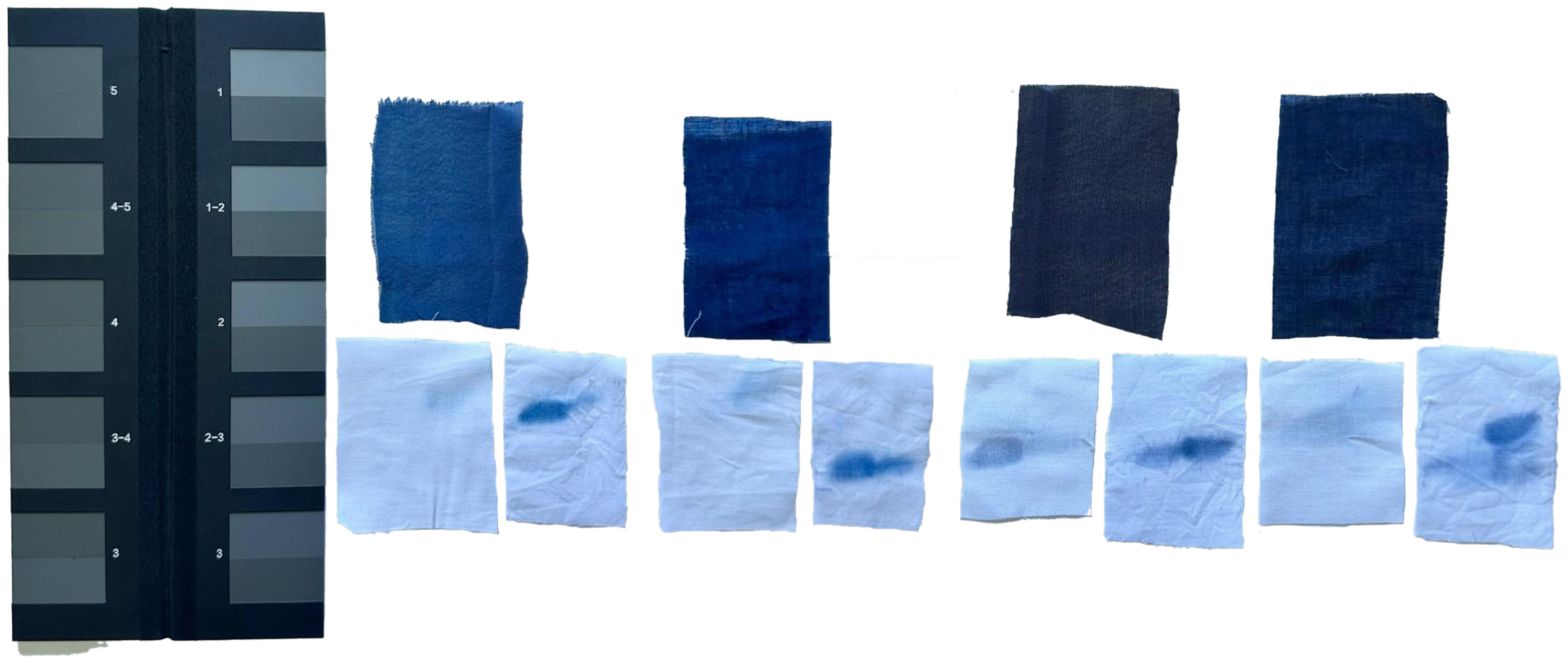
Run the full washing program

Air dry naturally; observe fading, staining,color change

Results – Rubbing Fastness

- Indigo Powder

Rubbing fastness-dry & wet rubbing, check color transfer.



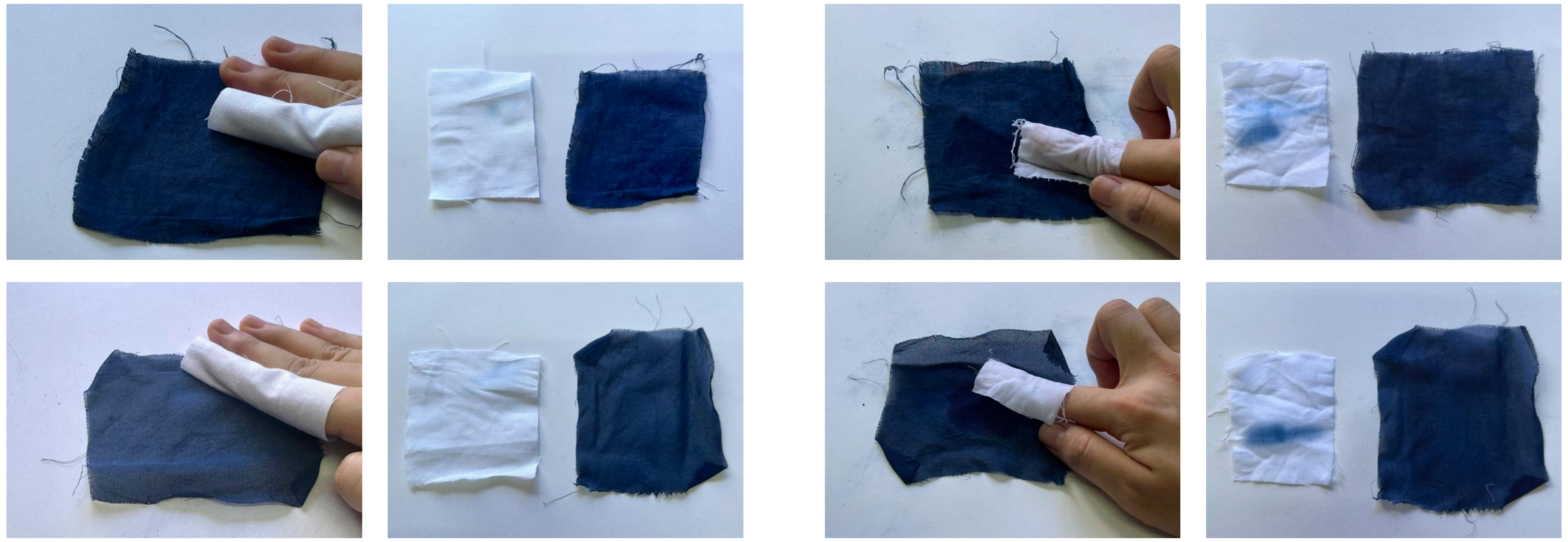
Figures 102 – 118. Indigo rubbing-fastness test, including ISO Grey Scale comparison (before/after rubbing) and full experimental workflow. All photographs by author.

Observation: The indigo-dyed cotton and yarn fabric showed obvious color staining under wet rubbing, but only slight staining under dry rubbing.

Bullet point: Indigo | 2 | Noticeable staining under wet rubbing |

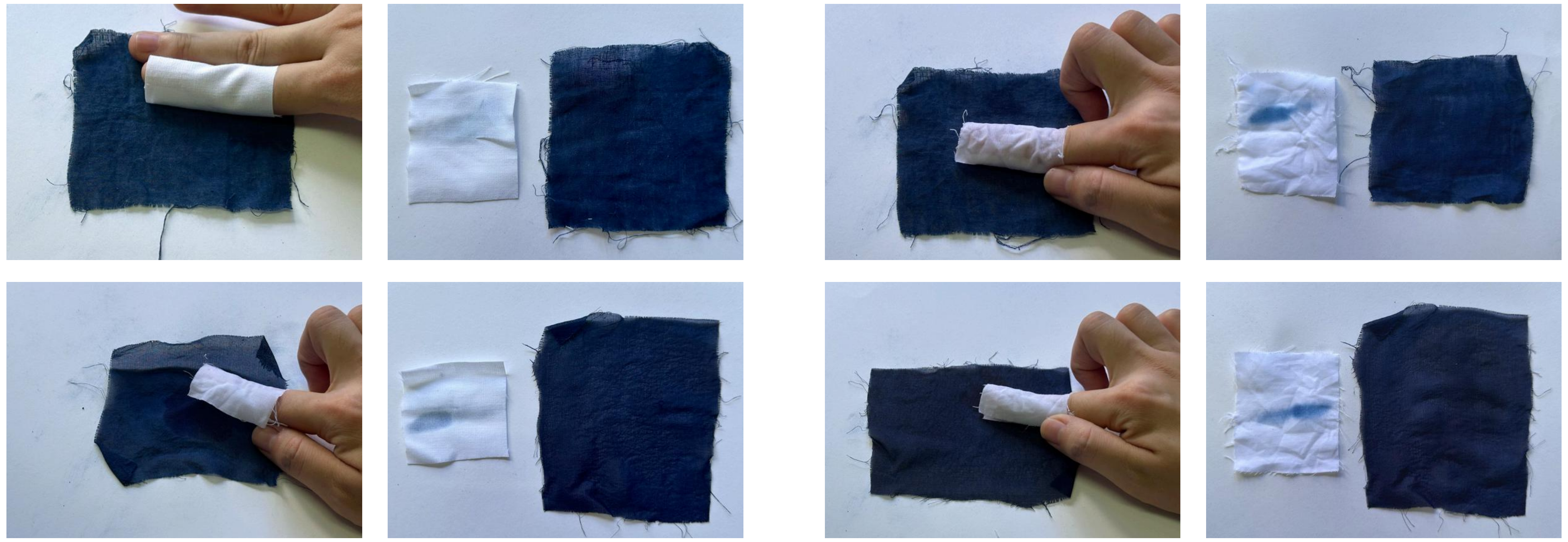
1min indigo powder – silk and cotton

Dry friction | Wet friction



60min indigo powder – silk and cotton

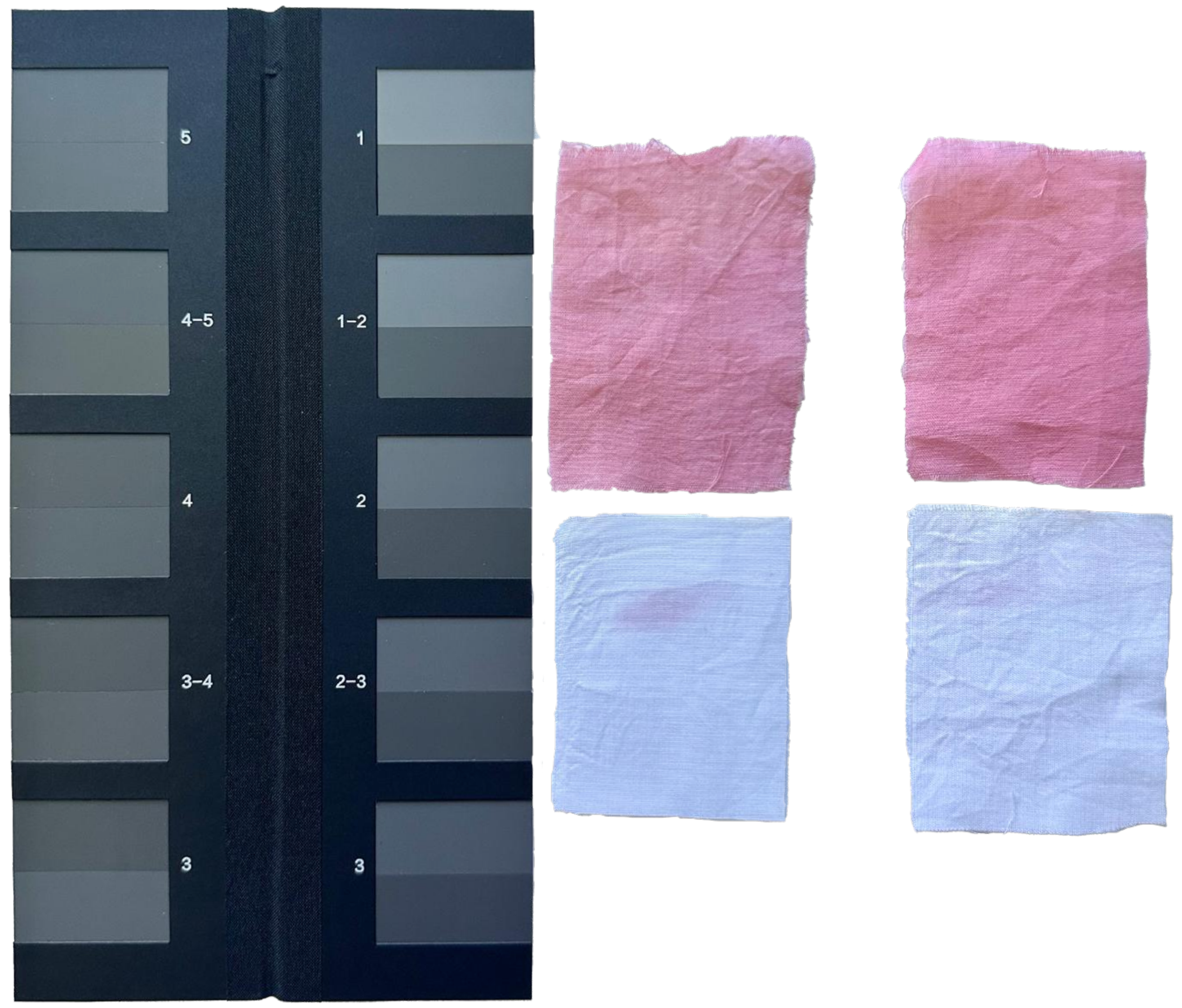
Dry friction | Wet friction



Results – Rubbing Fastness

• Chinese Madder

Rubbing fastness-dry & wet rubbing, check color transfer.



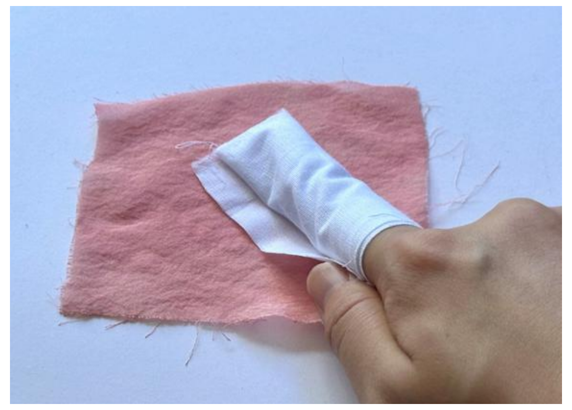
Figures 119 – 129. China Madder rubbing-fastness test, including ISO Grey Scale comparison (before/after rubbing) and full experimental workflow.
All photographs by author.

Observation: Both the untreated and Tannin (gallnut) fabrics showed nearly no staining after dry rubbing, but slight color transfer occurred under wet rubbing.

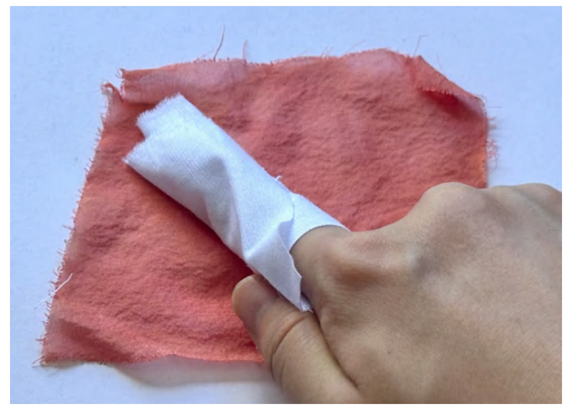
Bullet point: Madder | 3–4 | Good dry rubbing but slight staining when wet |

Madder – silk and cotton

Dry friction

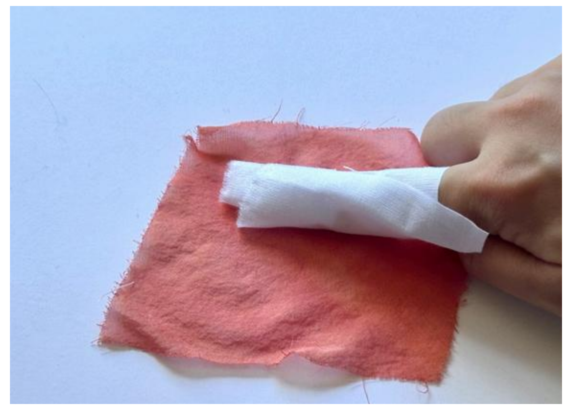


Wet friction



Madder with gallnut – silk and cotton

Dry friction



Wet friction

Results – Rubbing Fastness

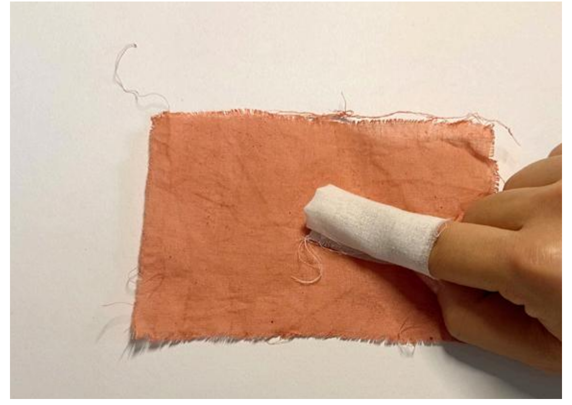
- Indian Madder

Rubbing fastness-dry & wet rubbing, check color transfer.

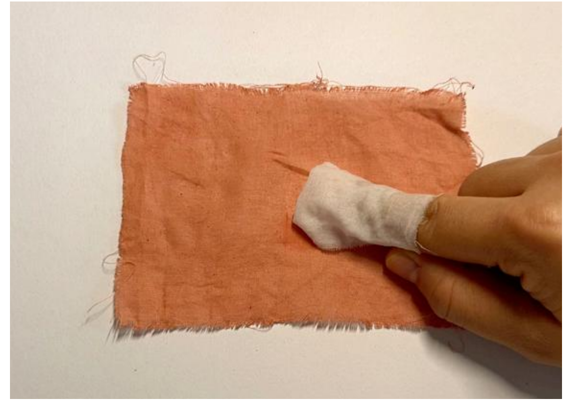
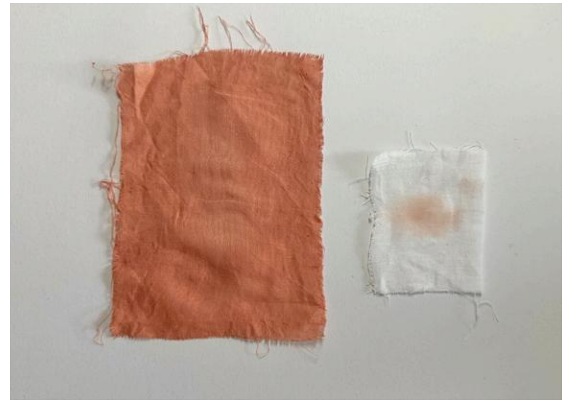
Figures 130 – 138. India Madder rubbing-fastness test, including ISO Grey Scale comparison (before/after rubbing) and full experimental workflow.
All photographs by author.

Madder – cotton

Dry friction

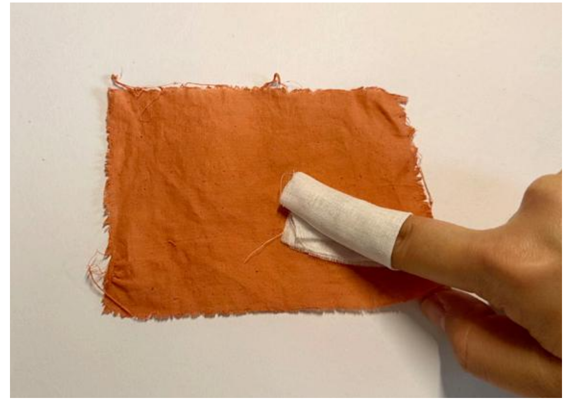
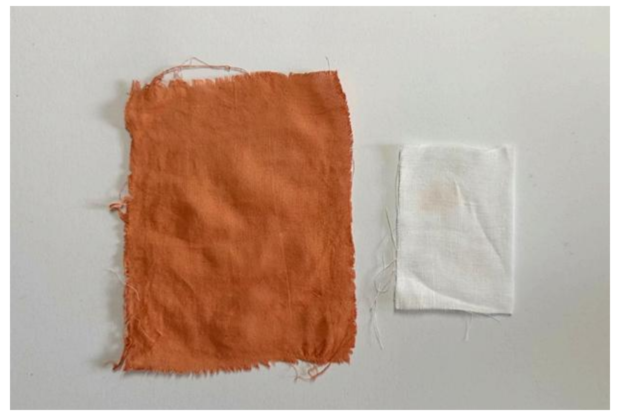



Wet friction

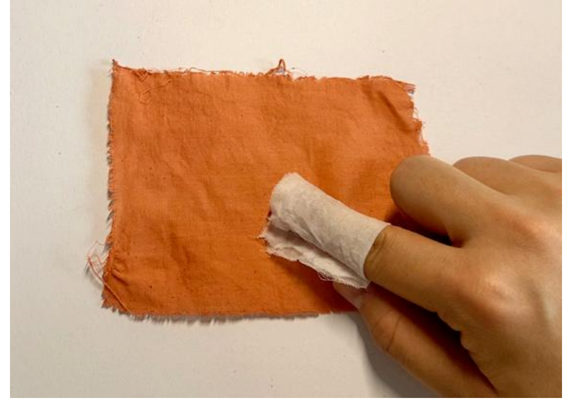



Madder with gallnut – cotton

Dry friction

Wet friction



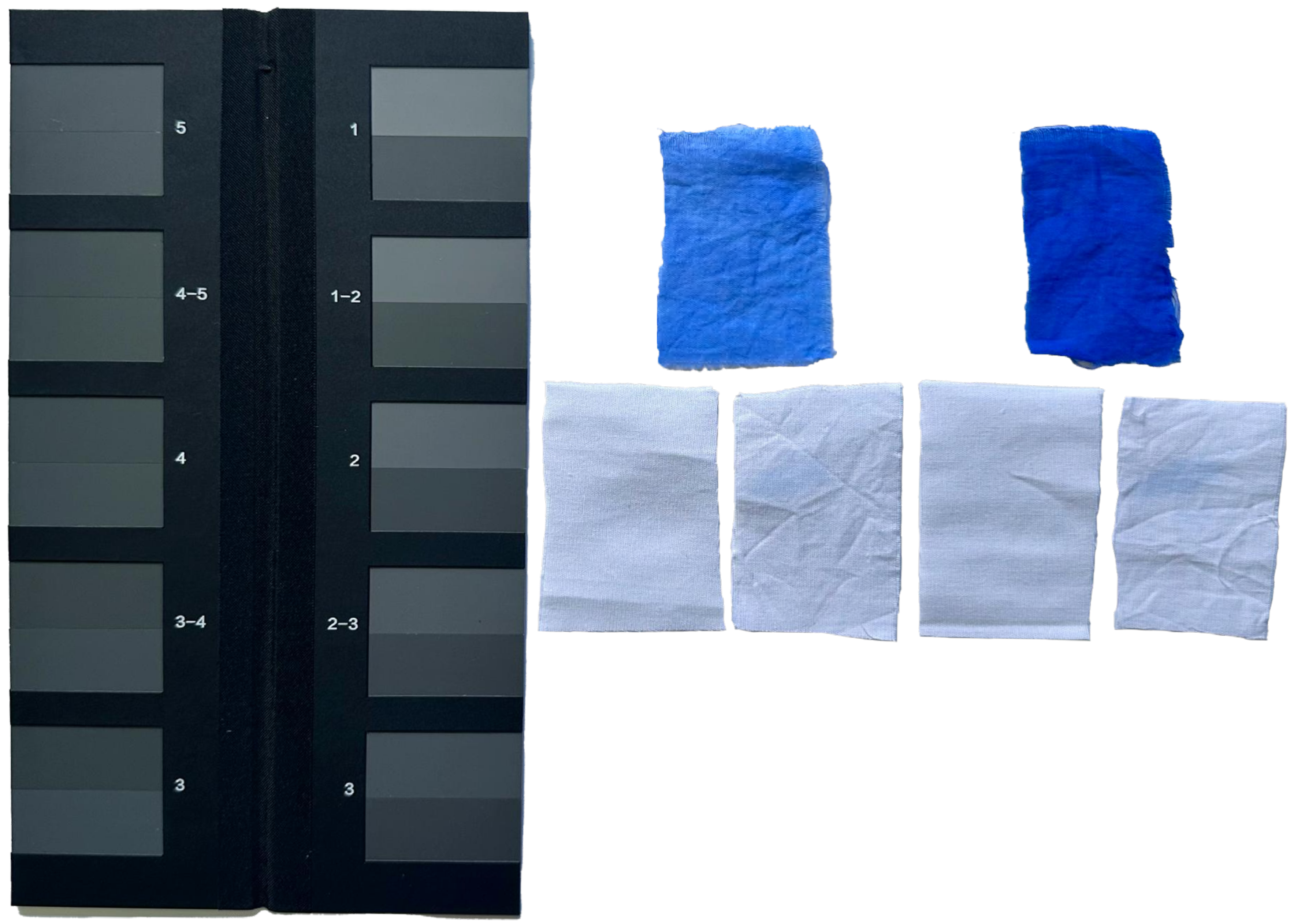

Observation: Both the untreated and Tannin (gallnut) fabrics showed nearly no staining after dry rubbing, but slight color transfer occurred under wet rubbing.

Bullet point: Madder | 3 | Good dry rubbing but slight staining when wet |

Results – Rubbing Fastness

- Reactive Blue 19

Rubbing fastness-dry & wet rubbing, check color transfer.



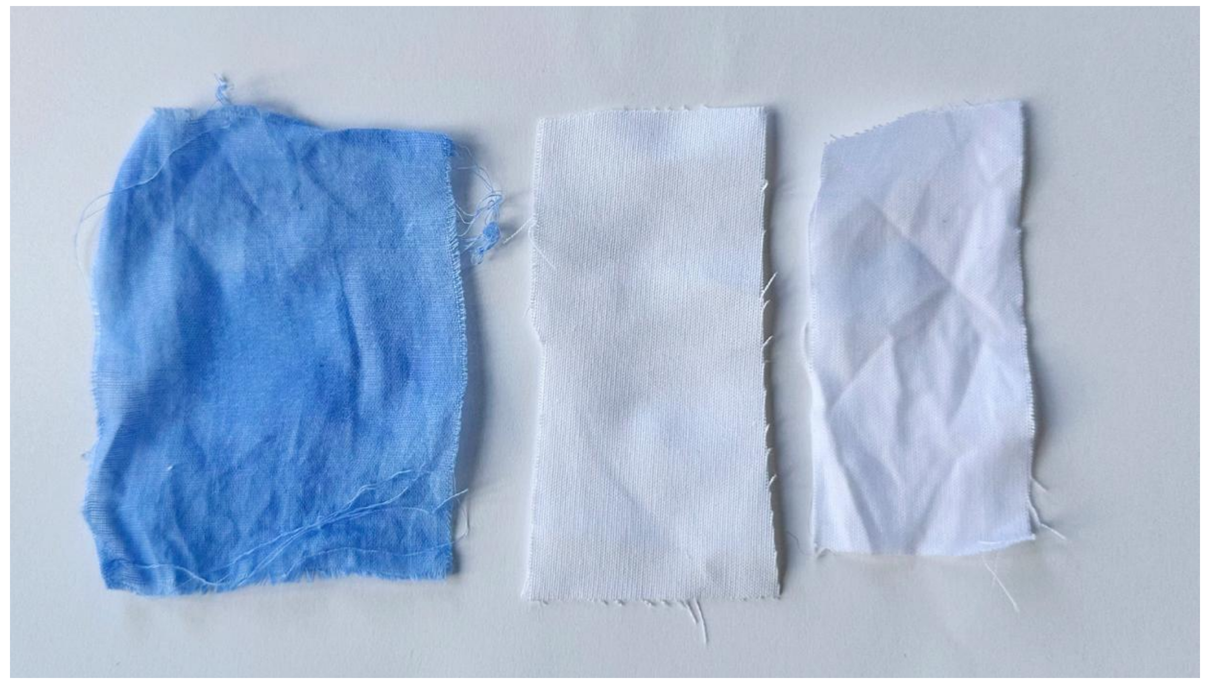
Figures 139 – 143. RB19 rubbing-fastness test, including ISO Grey Scale comparison (before/after rubbing) and full experimental workflow.
All photographs by author.

Observation: The Reactive Blue 19 fabric showed only a trace of color transfer after rubbing.

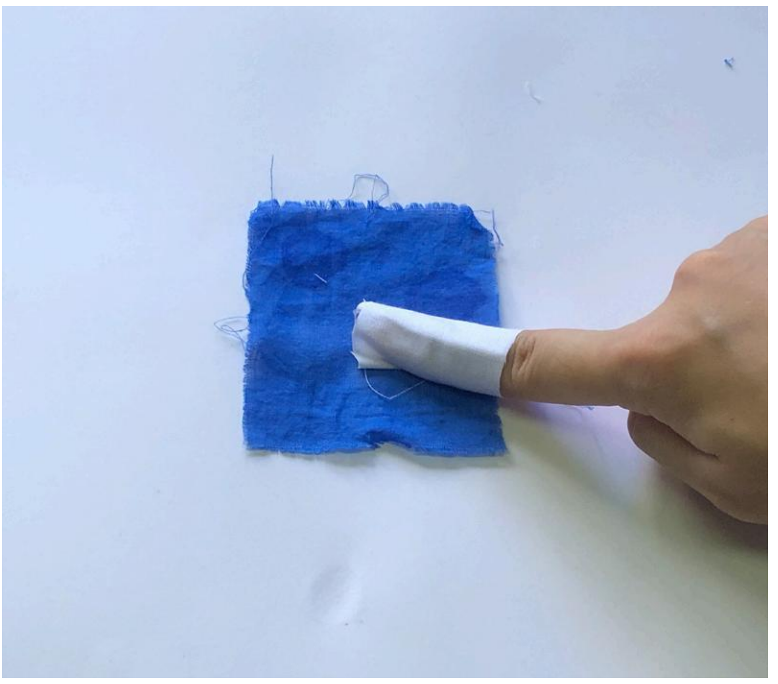
Bullet point: | RB19 | 4–5 | Minimal color transfer |

15min Reactive Blue 19 – cotton

Dry friction and Wet friction



60min Reactive Blue 19 – cotton

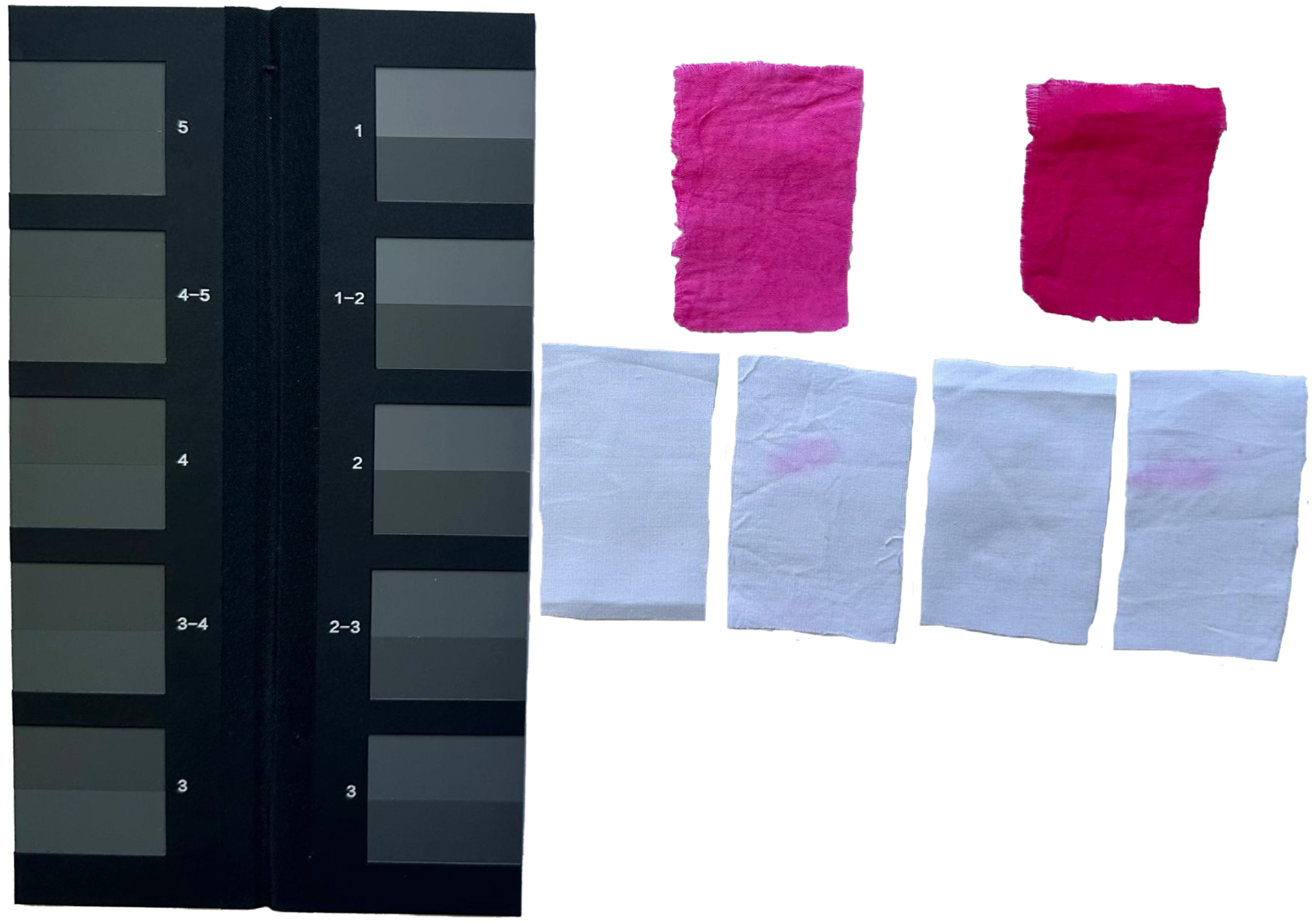


Dry friction and Wet friction

Results – Rubbing Fastness

- Reactive Red 195

Rubbing fastness-dry & wet rubbing, check color transfer.

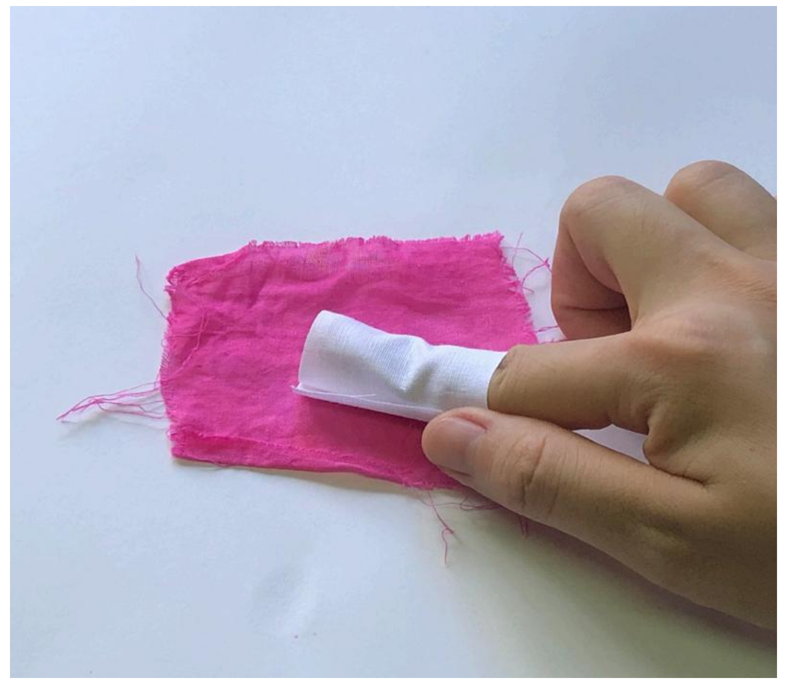


Figures 144 -148. RR195 rubbing-fastness test, including ISO Grey Scale comparison (before/after rubbing) and full experimental workflow.
All photographs by author.

Observation: The Reactive Red 195 fabric showed slight color transfer after rubbing.

Bullet point: | RR195 | 4–5 | Minimal color transfer |

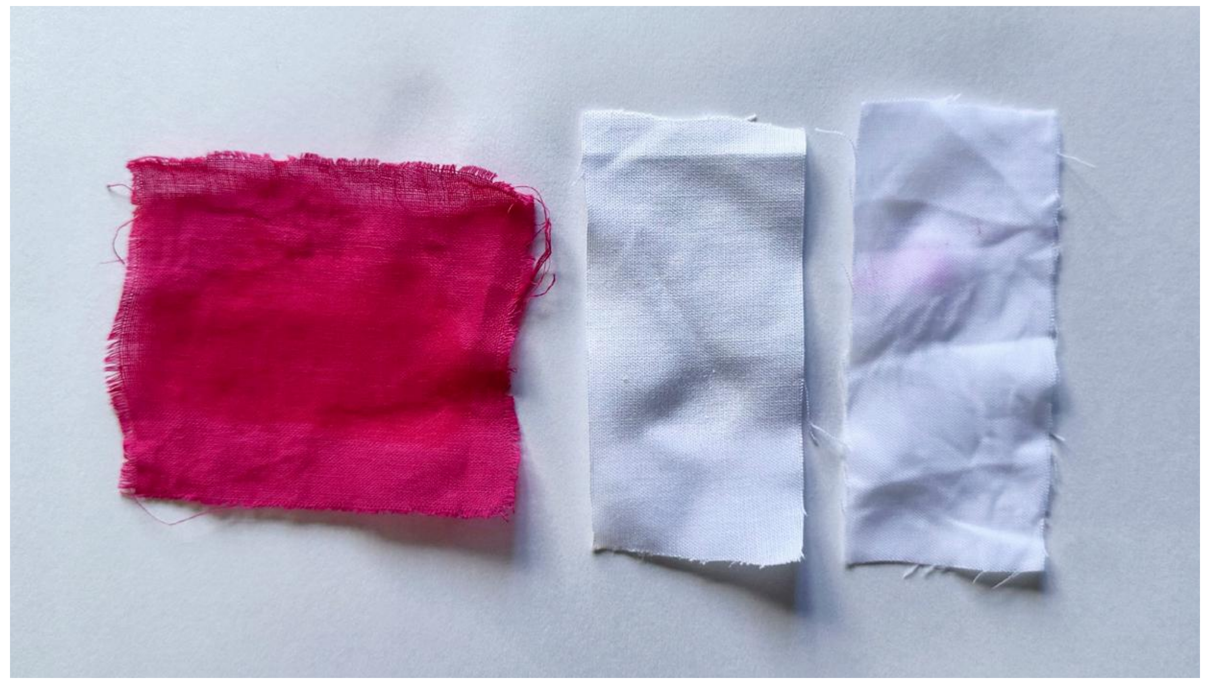
15min Reactive Red 195 – cotton



Dry friction and Wet friction

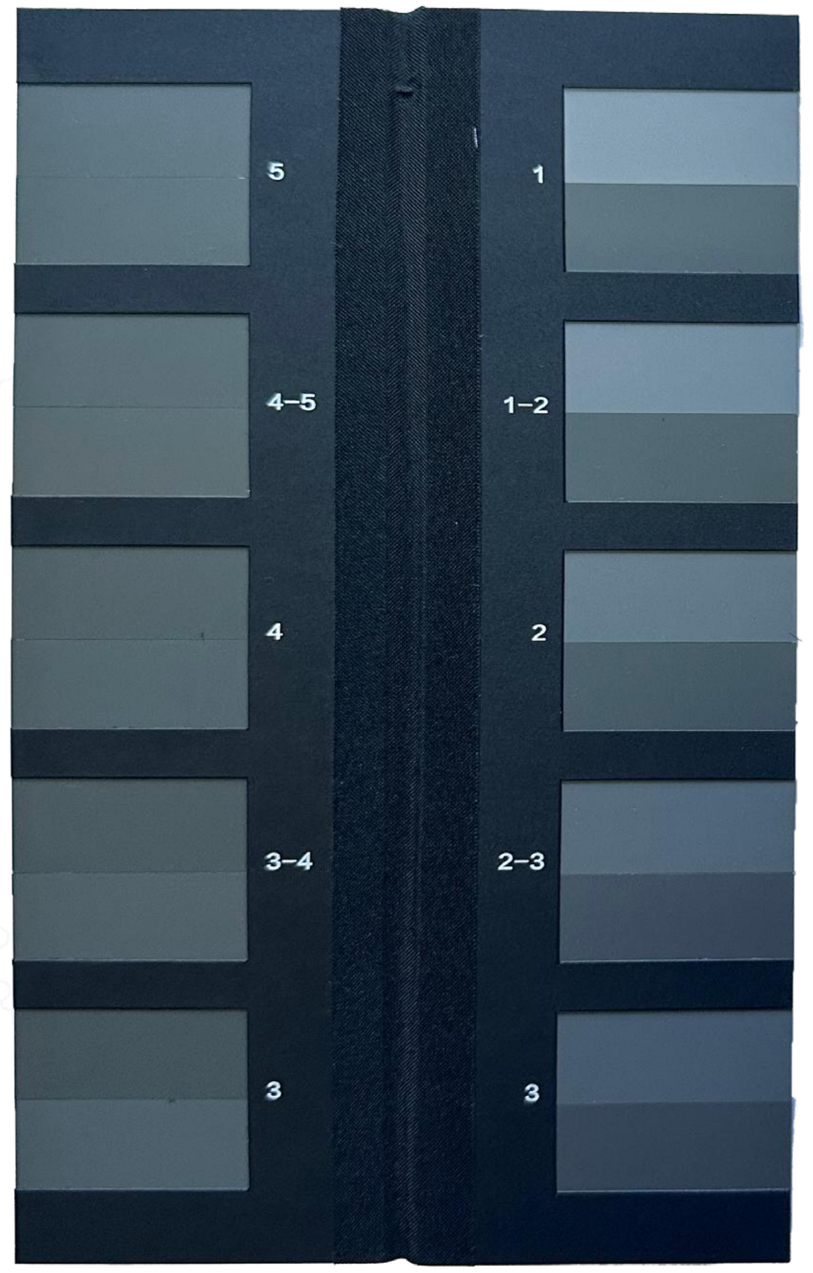
60min Reactive Red 195 – cotton

Dry friction and Wet friction



Results – Light Fastness

- Indigo Powder



Figures 149 – 154. Indigo light-fastness test, including ISO Grey Scale comparison (before/after light) and full experimental workflow.
All photographs by author.

Observation: The indigo fabric remained almost unchanged after being exposed to light for 24 hours.

Bullet point: Indigo | 4 | Good color retention |

Light fastness-expose to ISO light source (24h), record changes

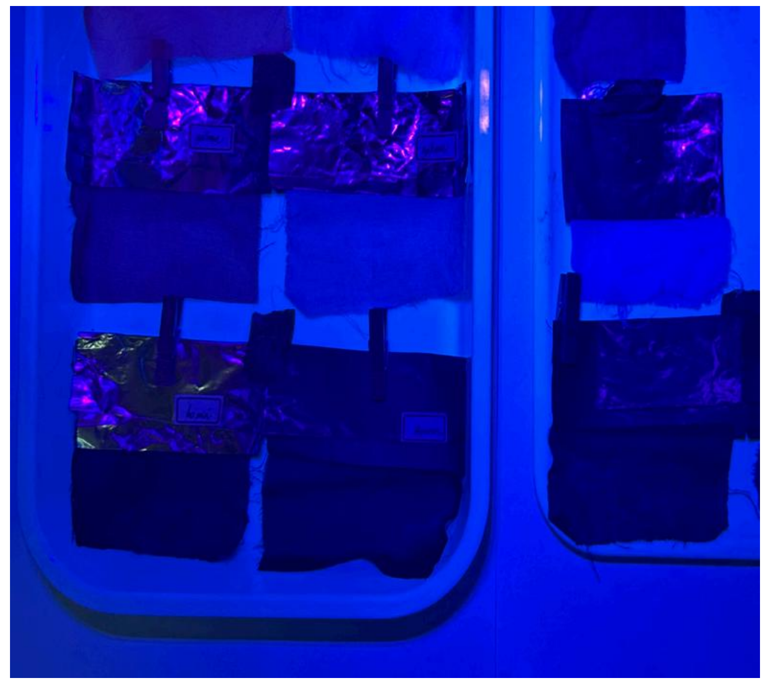
1 min Indigo powder
– silk and cotton

60 min Indigo powder
– silk and cotton

Half coverage is generally exposed

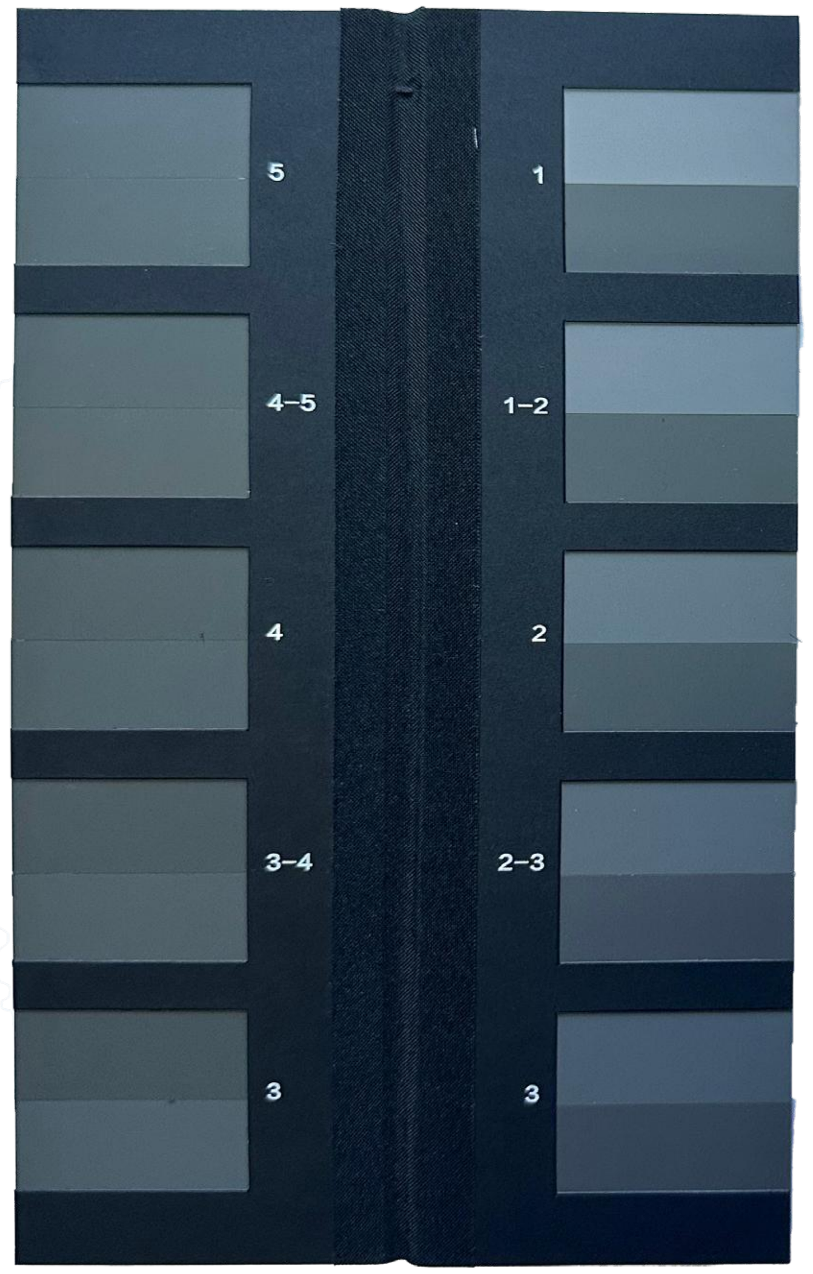
Simulate the effect of occlusion with tin foil

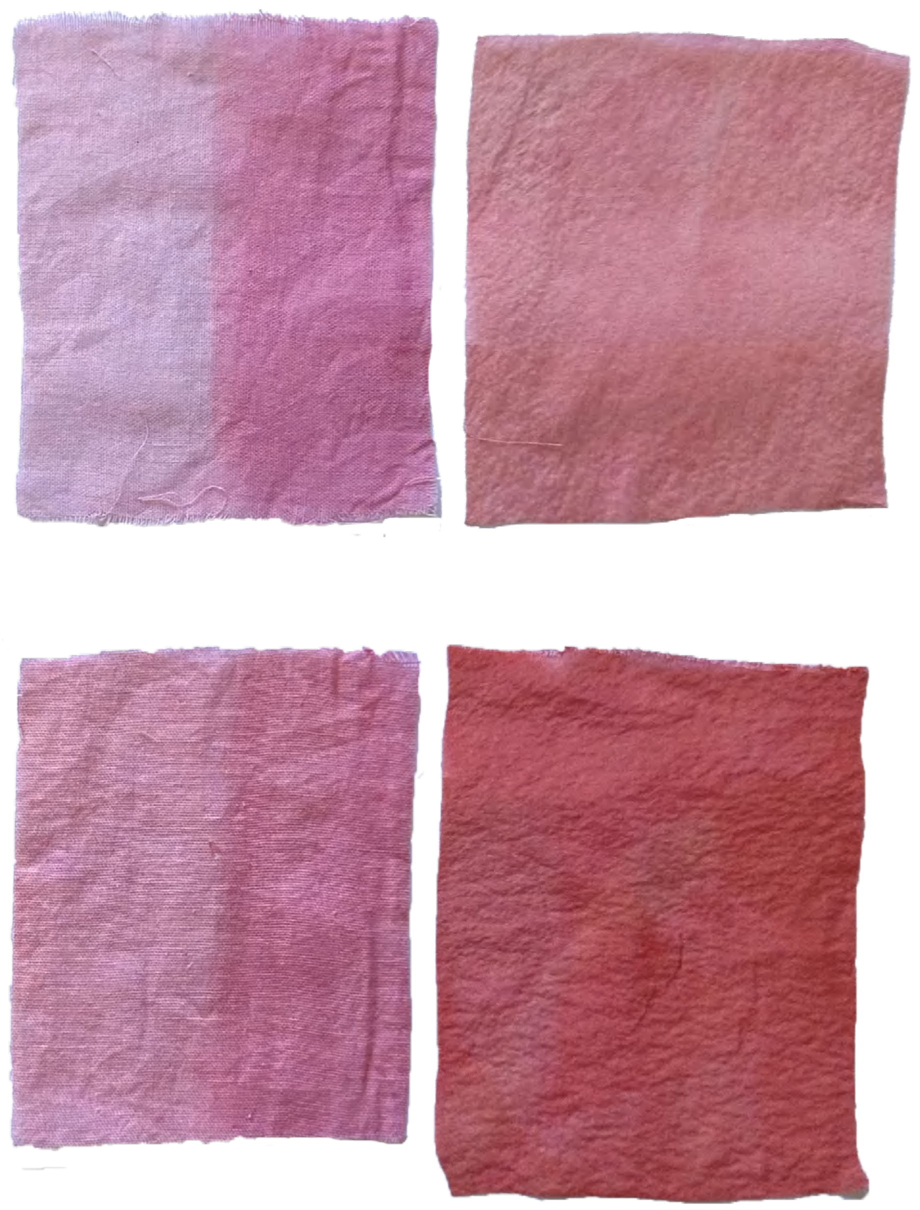
Exposed to ultraviolet light for 24 hours



Results – Light Fastness

- Chinese Madder





Figures 155 – 160. China Madder light-fastness test, including ISO Grey Scale comparison (before/after light) and full experimental workflow.
All photographs by author.

Observation: The untreated cotton fabric faded visibly after 24 hours of light, the Tannin cotton fabric faded slightly, and both silk fabrics showed mild uneven color loss.

Bullet point: Madder | 2–3 | Obvious fading after exposure |

Light fastness-expose to ISO light source (24h), record changes

Madder – silk and cotton

Madder with gallnut
– silk and cotton

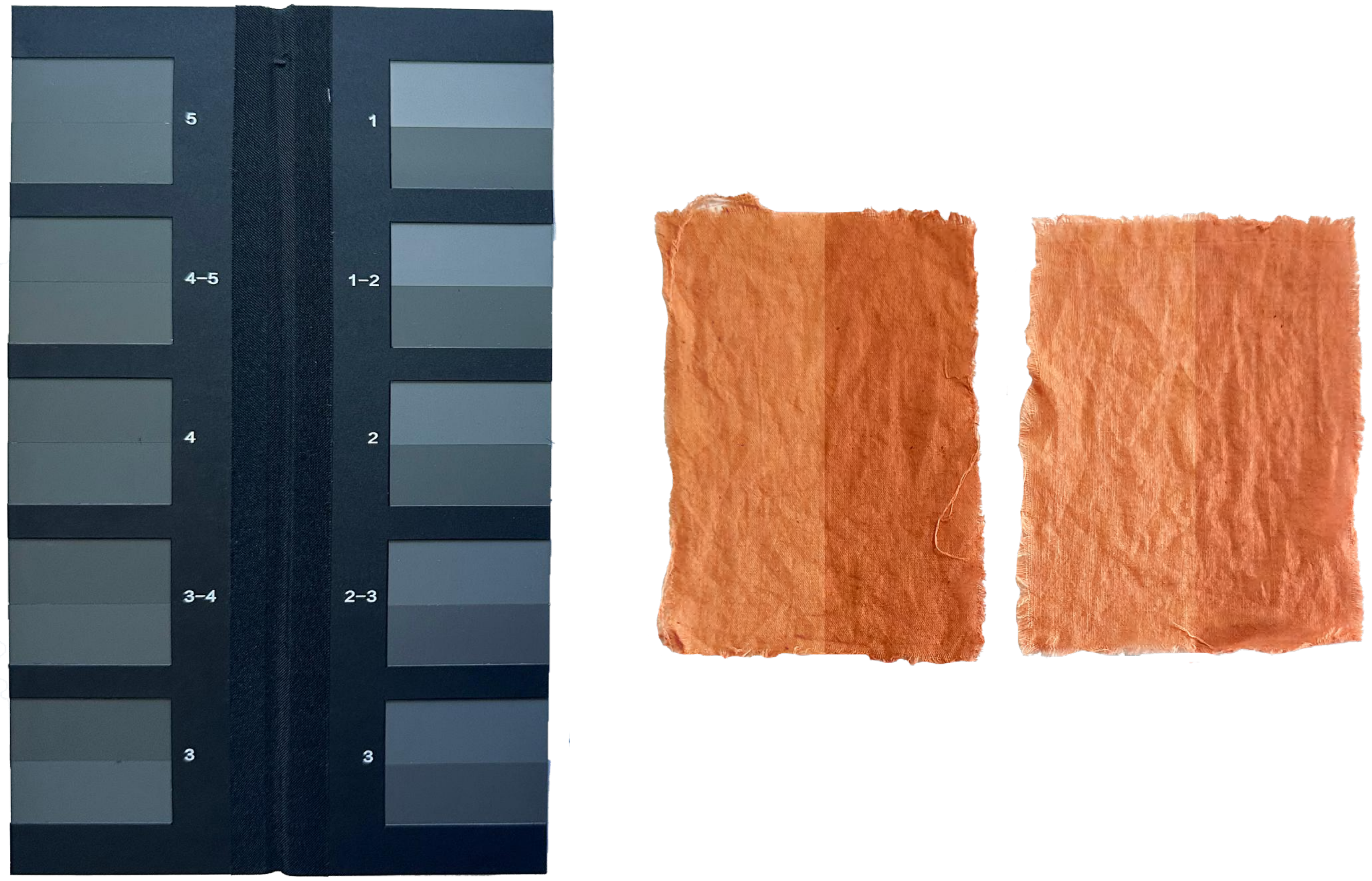
Simulate the effect of occlusion with tin foil

Half coverage is generally exposed

Exposed to ultraviolet light for 24 hours

Results – Light Fastness

- Indian Madder



Figures 161 – 166. India Madder light-fastness test, including ISO Grey Scale comparison (before/after light) and full experimental workflow.
All photographs by author.

Observation: The untreated cotton fabric faded visibly after 24 hours of light, the Tannin cotton fabric faded slightly, and both silk fabrics showed mild uneven color loss.

Bullet point: Madder | 3–4 | Obvious fading after exposure |

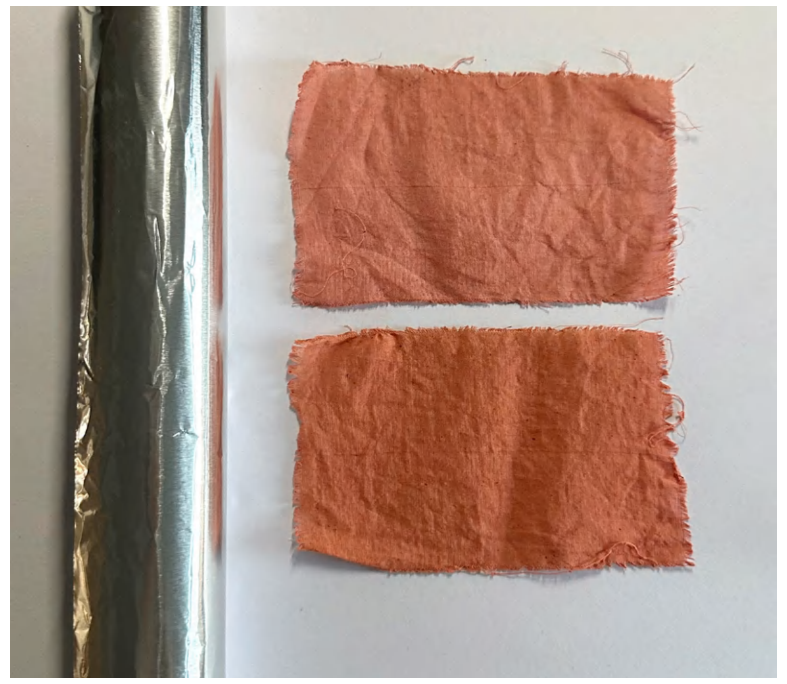
Light fastness-expose to ISO light source (24h), record changes

Madder – cotton

Madder with gallnut – cotton

Half coverage is generally exposed

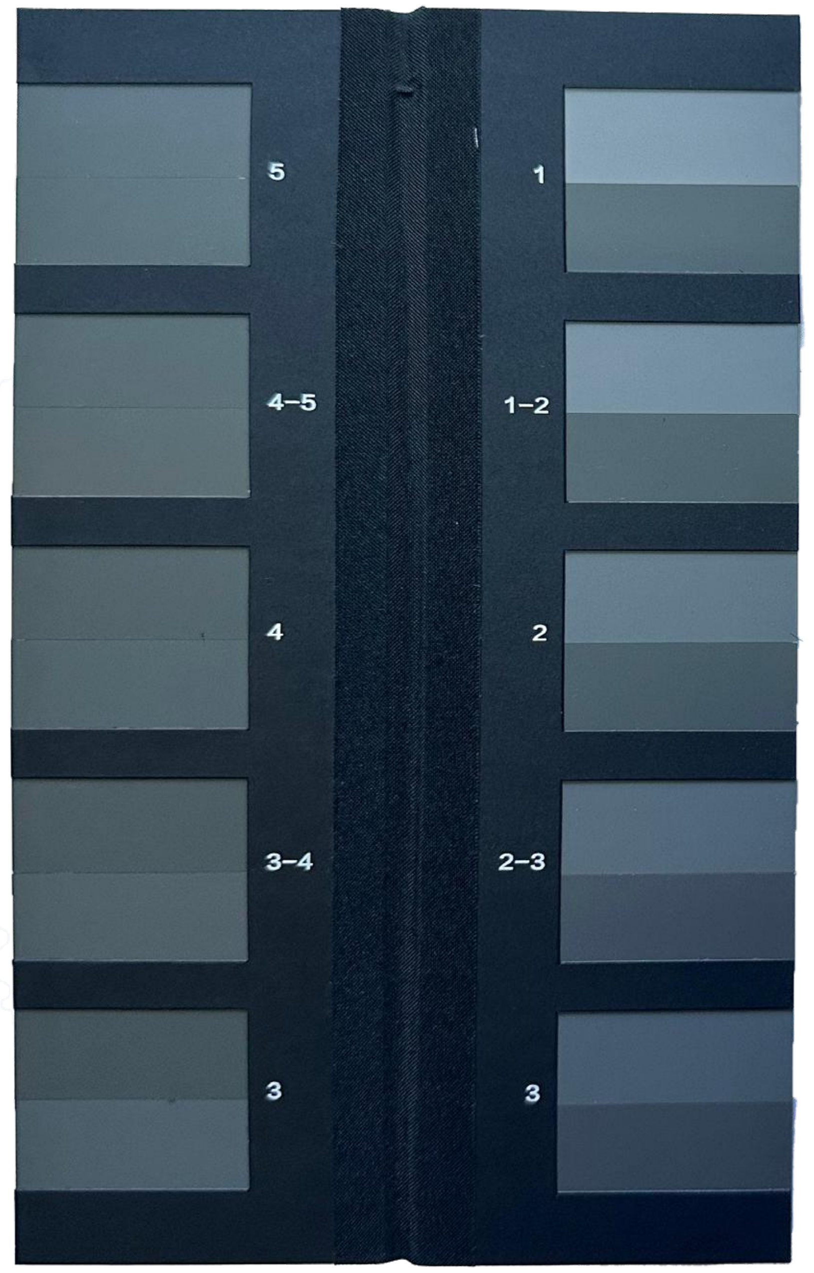
Simulate the effect of occlusion with tin foil

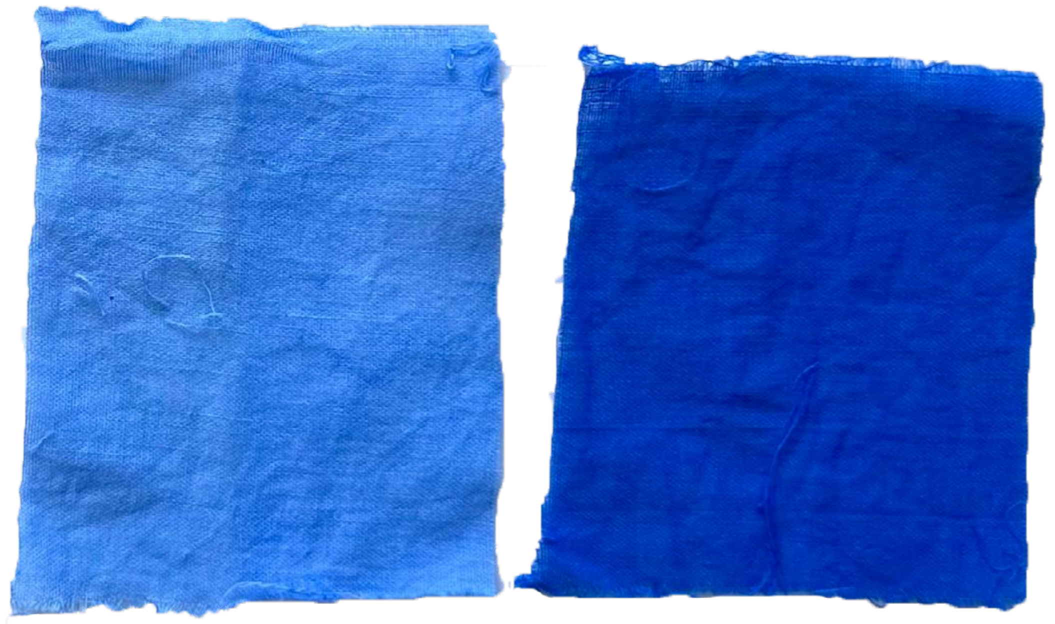


Exposed to ultraviolet light for 24 hours

Results – Light Fastness

- Reactive Blue 19





Figures 167 – 171. RB19 light-fastness test, including ISO Grey Scale comparison (before/after light) and full experimental workflow. All photographs by author.

Observation: The Reactive Blue 19 fabric showed mild fading after being exposed to light for 24 hours.

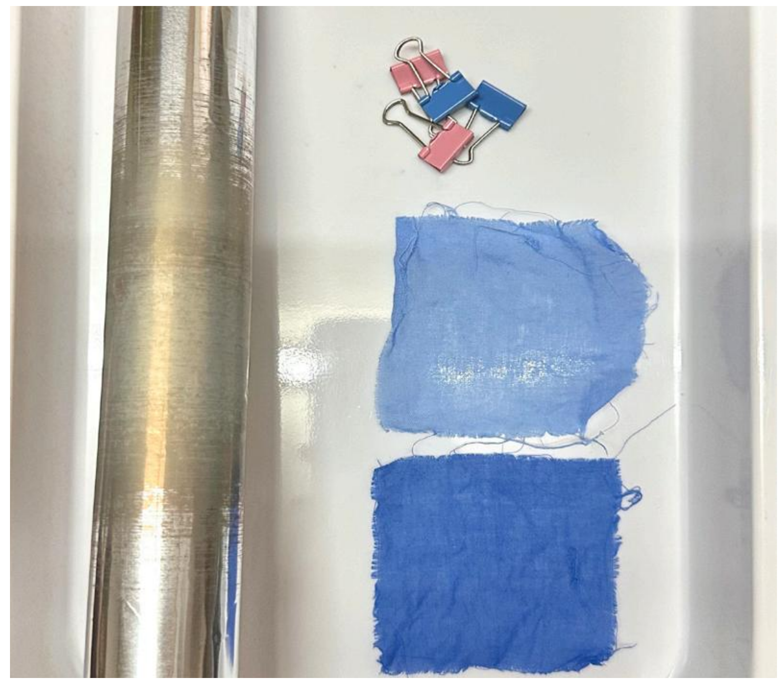
Bullet point: | RB19 | 4–5 | Excellent light fastness |

Light fastness-expose to ISO light source (24h), record changes

15min RB19 – cotton

60min RB19 – cotton

Simulate the effect of occlusion with tin foil

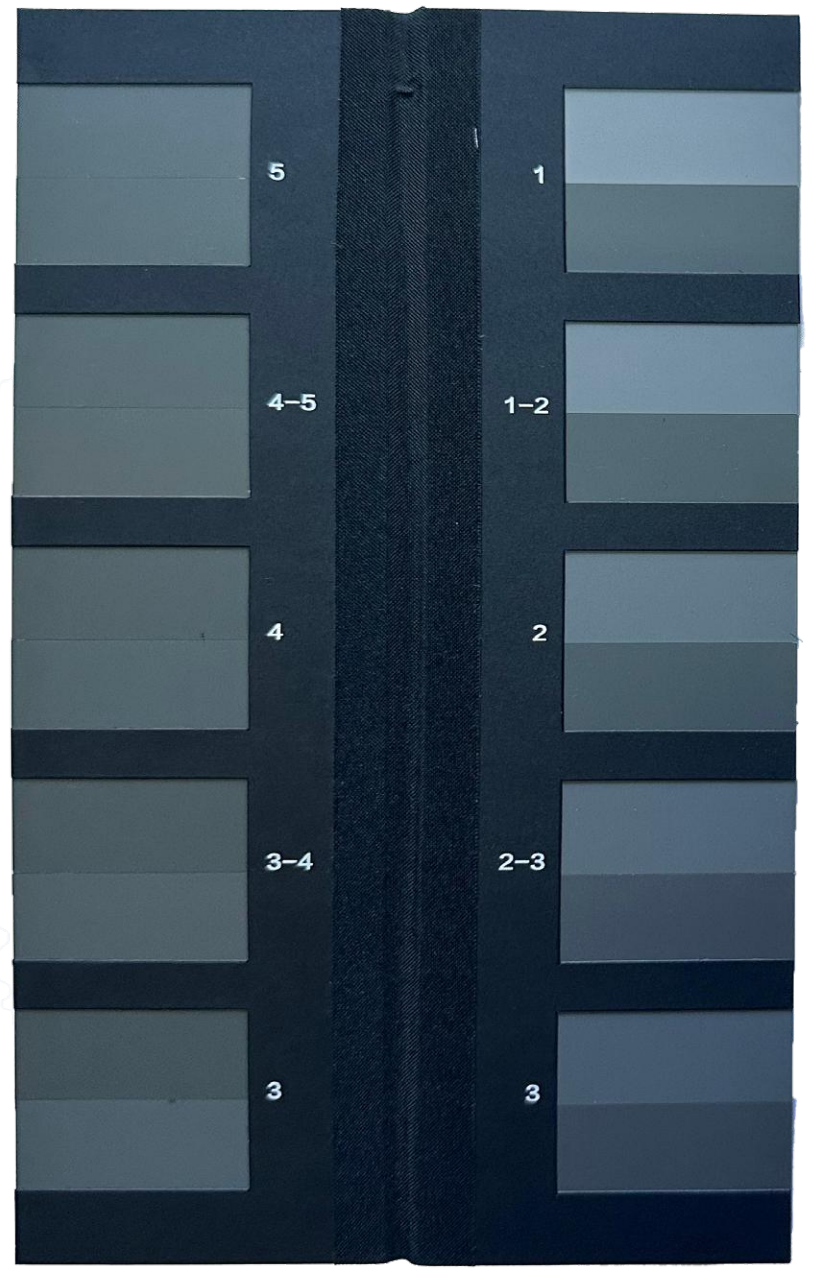


Half coverage is generally exposed

Exposed to ultraviolet light for 24 hours

Results – Light Fastness

- Reactive Red 195



Figures 172 – 176. RR195 light-fastness test, including ISO Grey Scale comparison (before/after light) and full experimental workflow. All photographs by author.

Observation: The Reactive Red 195 fabric showed only a very slight fading after 24 hours of light exposure.

Bullet point: | RR195 | 4–5 | Excellent light fastness |

Light fastness-expose to ISO light source (24h), record changes

15min RR195 – cotton

15min RR195 – cotton

Simulate the effect of occlusion with tin foil

Half coverage is generally exposed

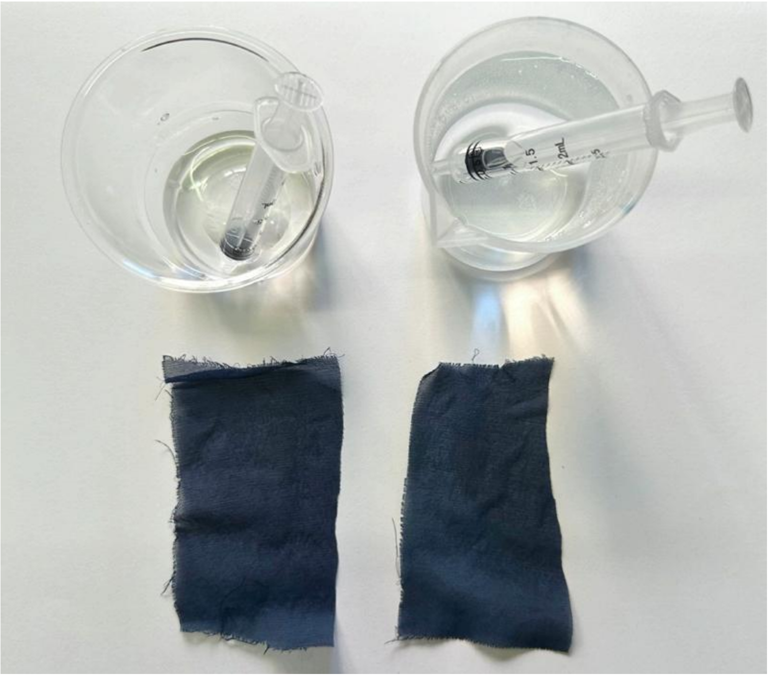
Exposed to ultraviolet light for 24 hours

Results – Perspiration Fastness

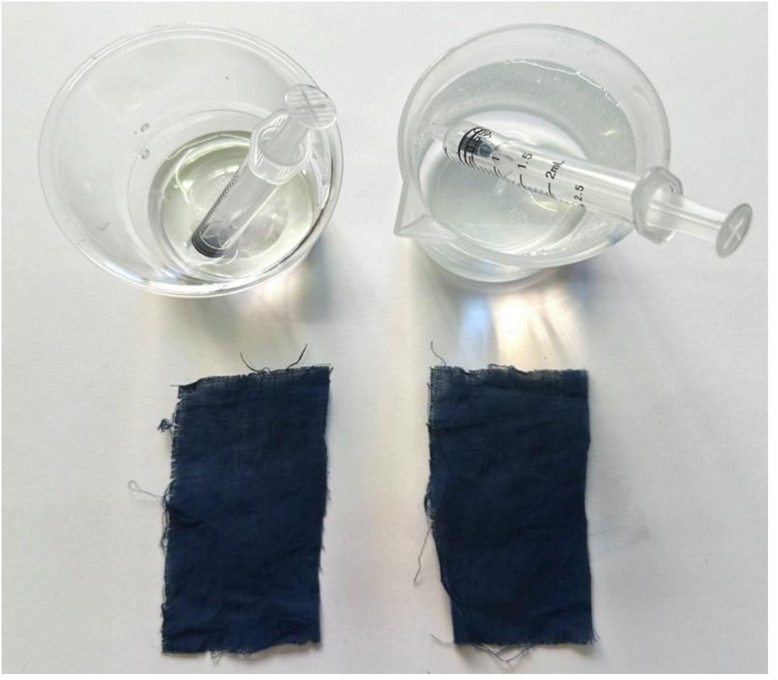
- Indigo Powder

Perspiration fastness-acidic/alkaline sweat solution, observe shade change.

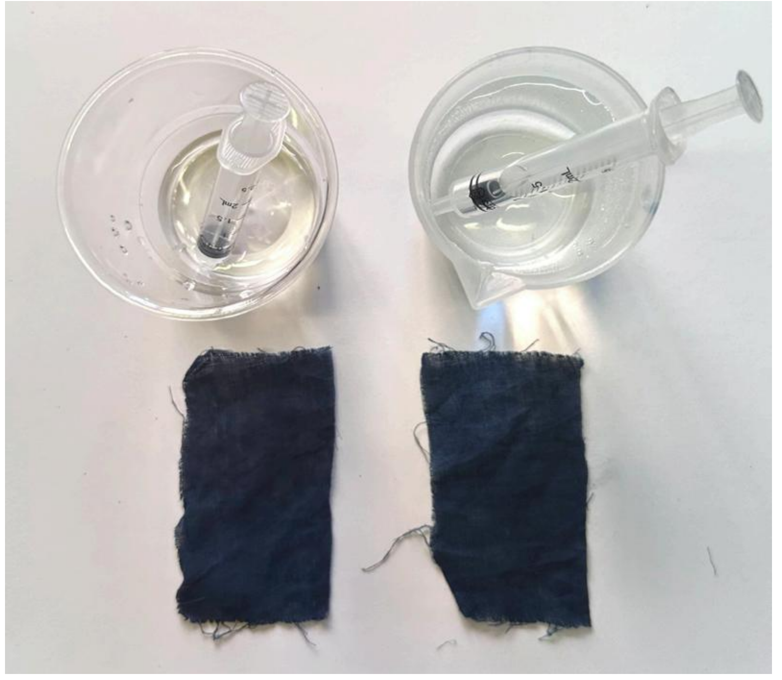
1min Indigo powder – cotton



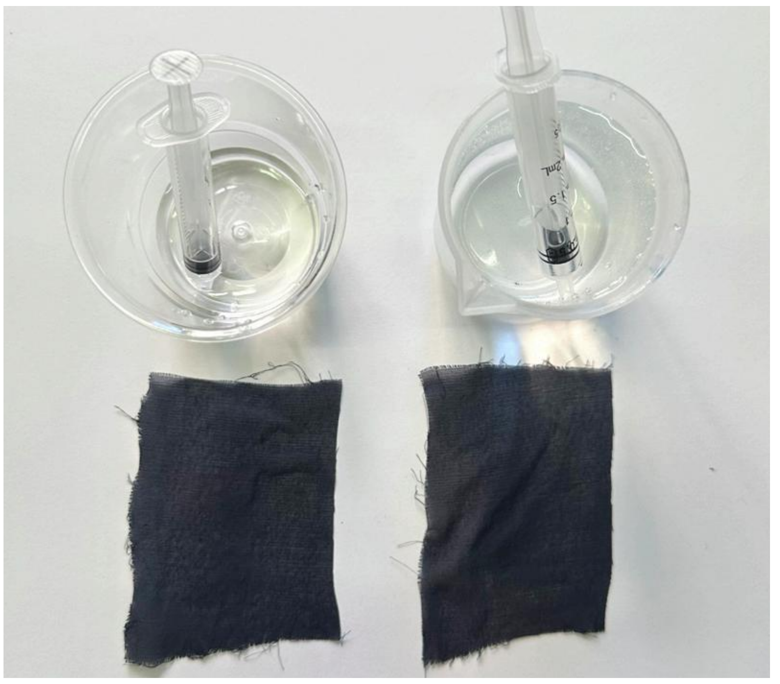
1min Indigo powder – silk



60min Indigo powder–cotton



60min Indigo powder – silk



Figures 177 – 182. Indigo perspiration-fastness test, including ISO Grey Scale comparison (before/after perspiration) and full experimental workflow. All photographs by author.

Observation: The indigo fabric remained almost unchanged after the perspiration test.

Bullet point: Indigo | 4 | Stable, with no significant change |

Results – Perspiration Fastness

- Chinese Madder

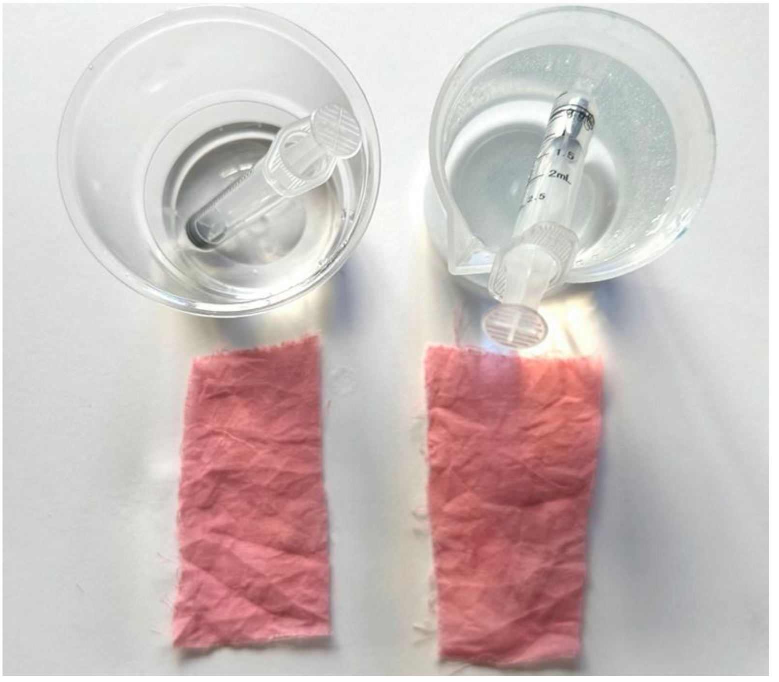
Figures 183 – 187. China Madder perspiration-fastness test, including ISO Grey Scale comparison (before/after perspiration) and full experimental workflow. All photographs by author.

Observation: The untreated silk fabric showed uneven fading under acidic perspiration, while the Tannin silk fabric showed only slight fading. Other samples showed almost no change.

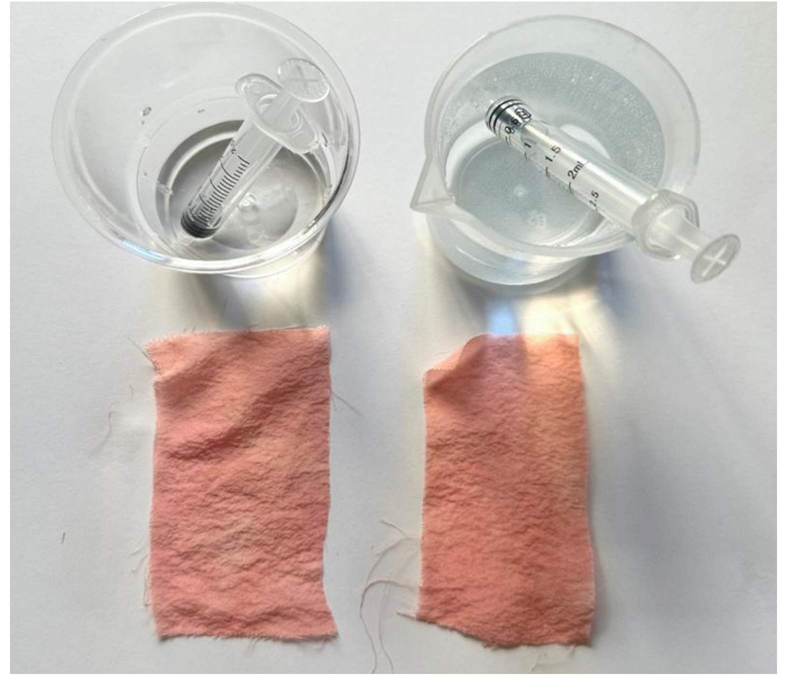
Bullet point: Madder | 3–4 | Slight color change observed |

Perspiration fastness-acidic/alkaline sweat solution, observe shade change.

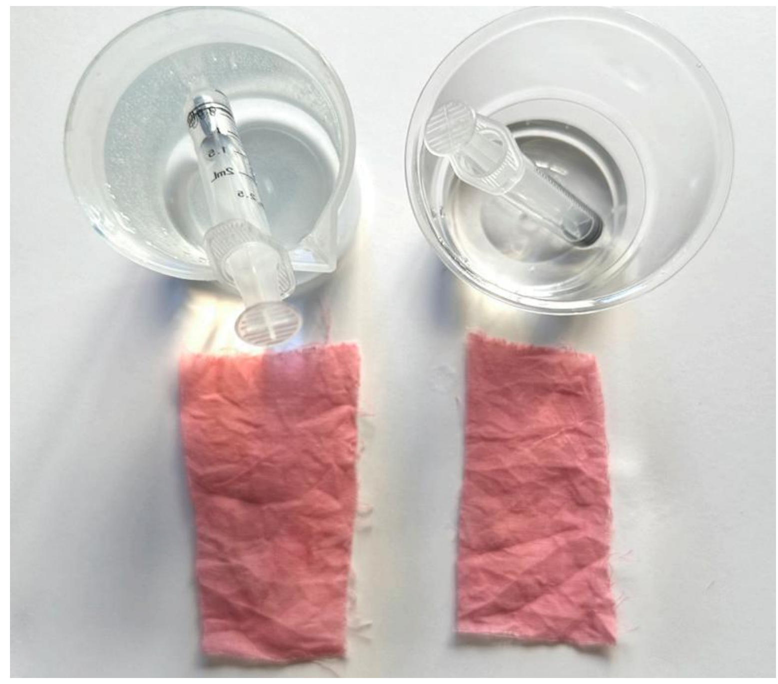
Madder – cotton



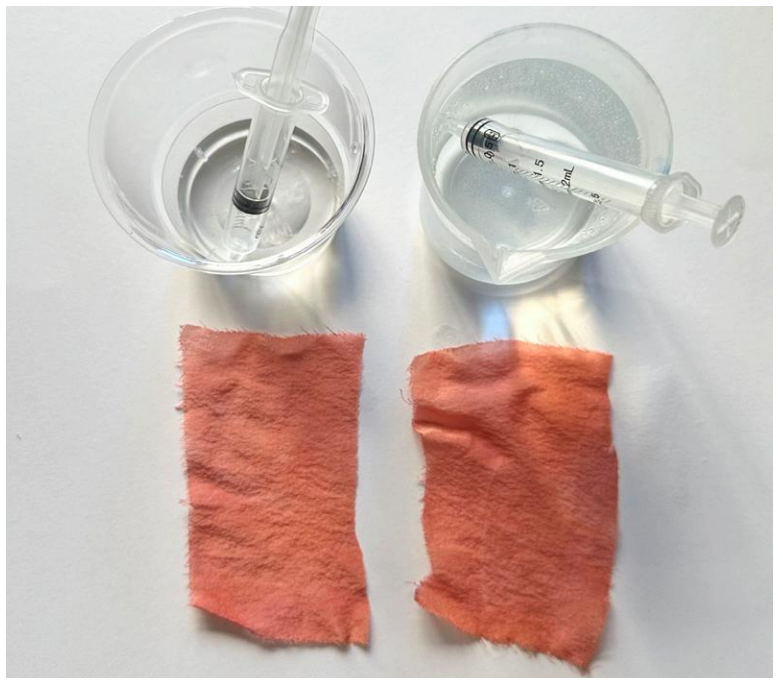
Madder –silk



Madder with gallnut – cotton



Madder with gallnut – silk



Results – Perspiration Fastness

- Indian Madder

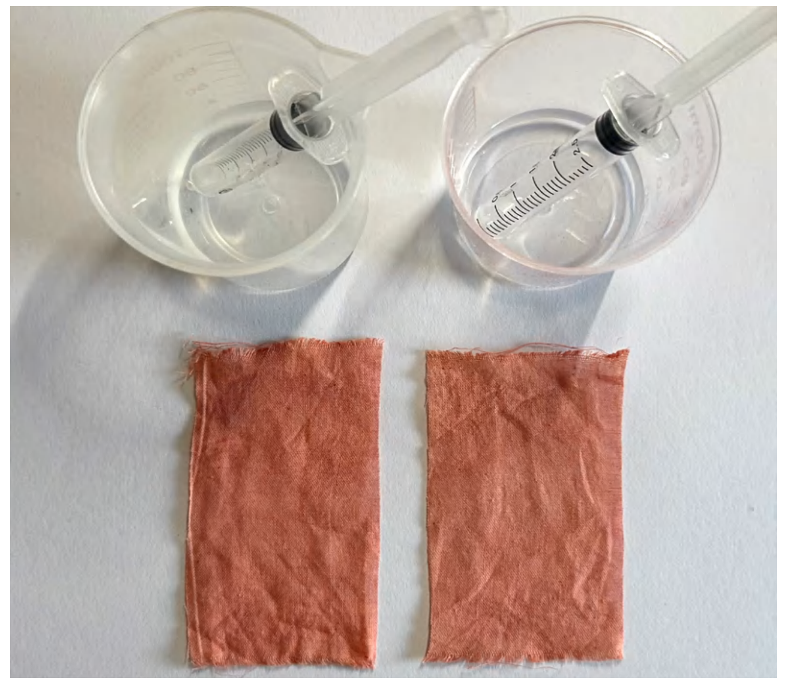
Figures 188 – 190. India Madder perspiration-fastness test, including ISO Grey Scale comparison (before/after perspiration) and full experimental workflow.
All photographs by author.

Observation: The untreated silk fabric showed uneven fading under acidic perspiration, while the Tannin silk fabric showed only slight fading.
Other samples showed almost no change.

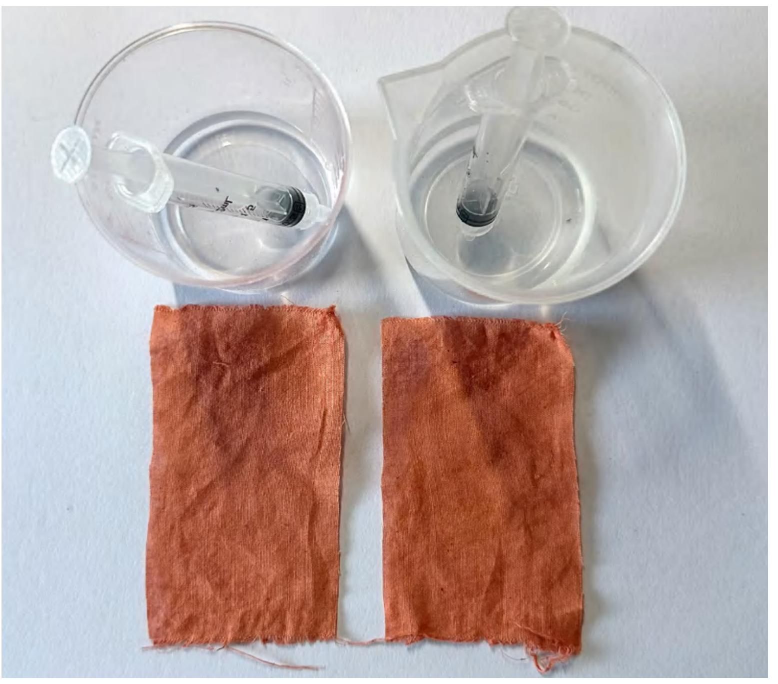
Bullet point: Madder | 3–4 | Slight color change observed |

Perspiration fastness-acidic/alkaline sweat solution, observe shade change.

Madder – cotton

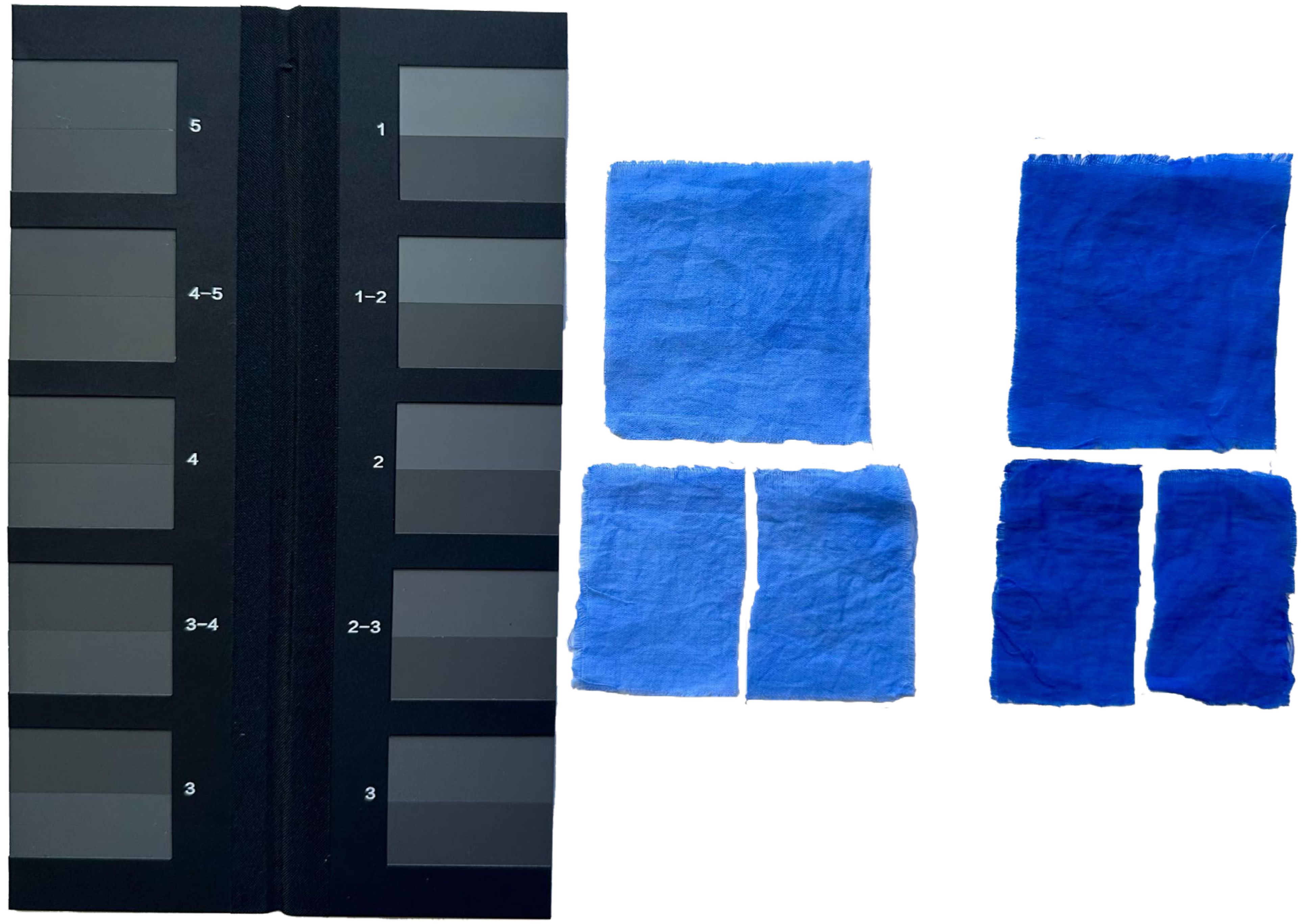


Madder with gallnut – cotton

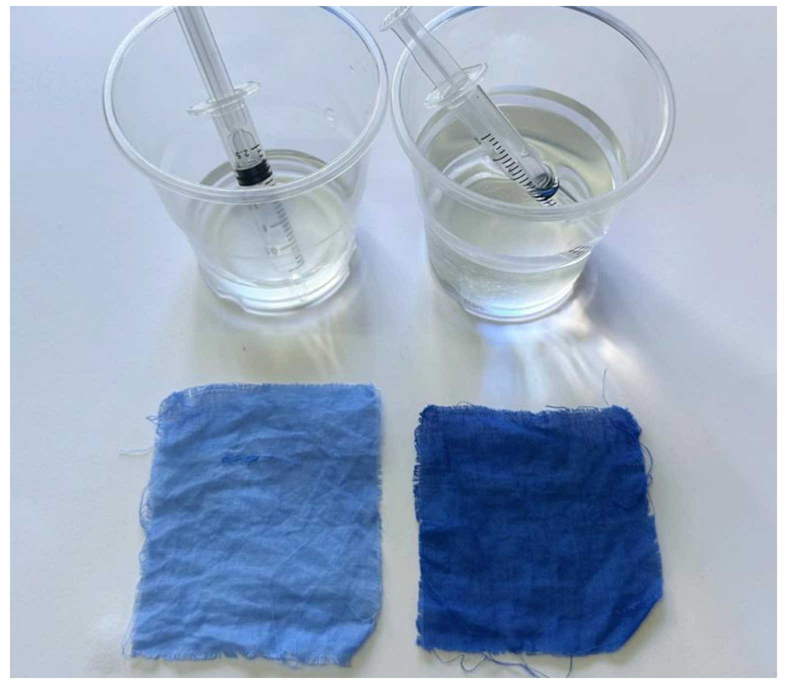


Results – Perspiration Fastness

- Reactive Blue 19

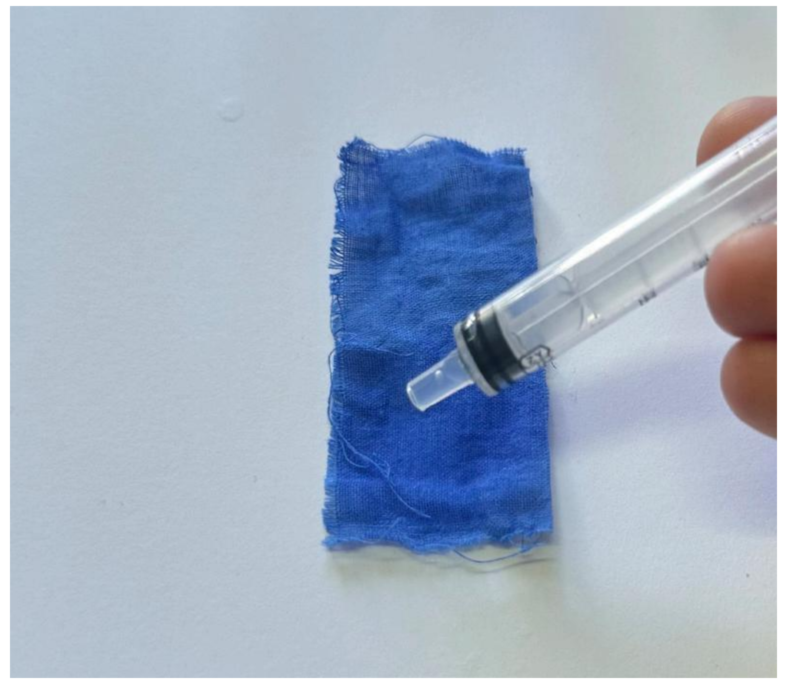


Perspiration fastness-acidic/alkaline sweat solution, observe shade change.



15min Reactive Blue 19 – cotton

60min Reactive Blue 19 – cotton



Figures 191 – 193. RB19 perspiration-test, including ISO Grey Scale comparison (before/after perspiration) and full experimental workflow. All photographs by author.

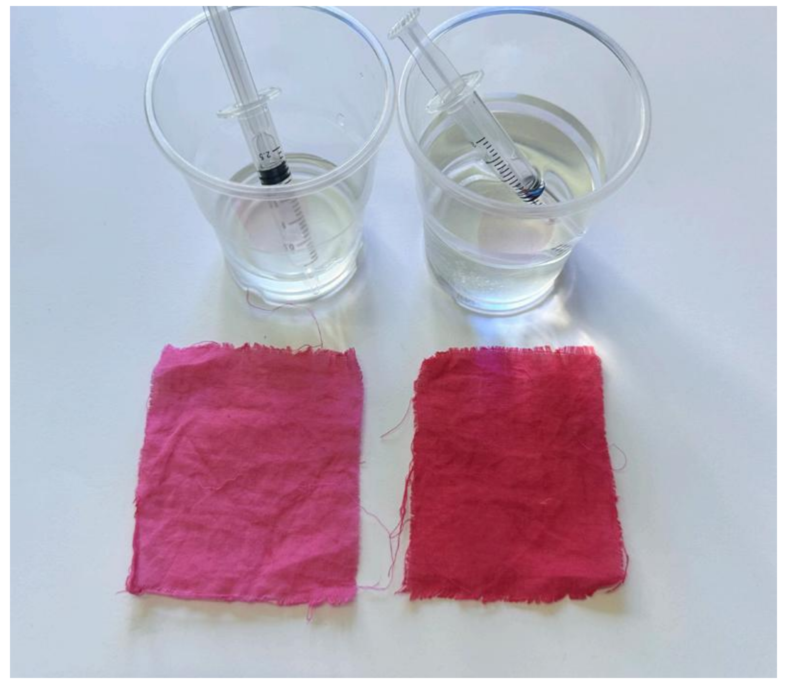
Observation: The fabric dyed with Reactive Blue 19 showed almost no change after the perspiration test.

Bullet point: | RB19 | 4–5 | Stable with no significant change |

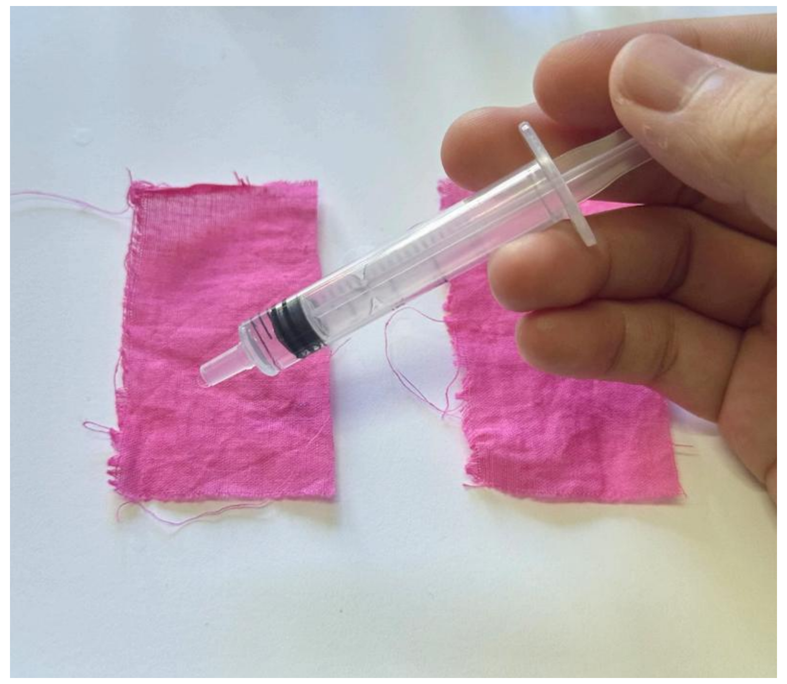
Results – Perspiration Fastness

- Reactive Red 195

Perspiration fastness-acidic/alkaline sweat solution, observe shade change.



15min Reactive Red 195 – cotton



60min Reactive Red 195 – cotton

Figures 194 – 196. RR195 perspiration-fastness test, including ISO Grey Scale comparison (before/after perspiration) and full experimental workflow.
All photographs by author.

Observation: The fabric dyed with Reactive Red 195 also showed almost no change after the perspiration test.

Bullet point: | RR195 | 4–5 | Stable with no significant change |

Fastness Evaluation Summary

- Summary of all fastness tests across dyes

Test Type	Dye	ISO Grade	Traffic Light	Notes
Washing Fastness	Indigo Powder	3–4		Slight fading, relatively stable performance.
	Chinese/Indian Madder	3–4		Slight fading, acceptable level.
	RB19/RR195	4–5		Excellent fastness, no visible colour loss.
Light Fastness	Indigo Powder	4		Good colour retention.
	Chinese/Indian Madder	2–3		Obvious fading.
	RB19/RR195	4–5		Excellent light stability.
Rubbing Fastness	Indigo Powder	2		Significant color transfer when wet.
	Chinese/Indian Madder	3–4		Good dry rub, mild wet stain.
	RB19/RR195	4–5		Stable, minimal transfer.
Perspiration Fastness	Indigo Powder	4		Stable, no visible change.
	Chinese/Indian Madder	3–4		Slight colour change in acidic.
	RB19/RR195	4–5		Stable, no visible change.
Machine Washing Fastness	Indigo Powder	3-4		Slight fading with acceptable performance
	Chinese Madder	2-3		Hue shifted from light pink to light orange
	Indian Madder	3–4		Slight fading with acceptable performance
	RB19/RR195	4		Excellent stability with slight fading

Traffic-Light Evaluation System

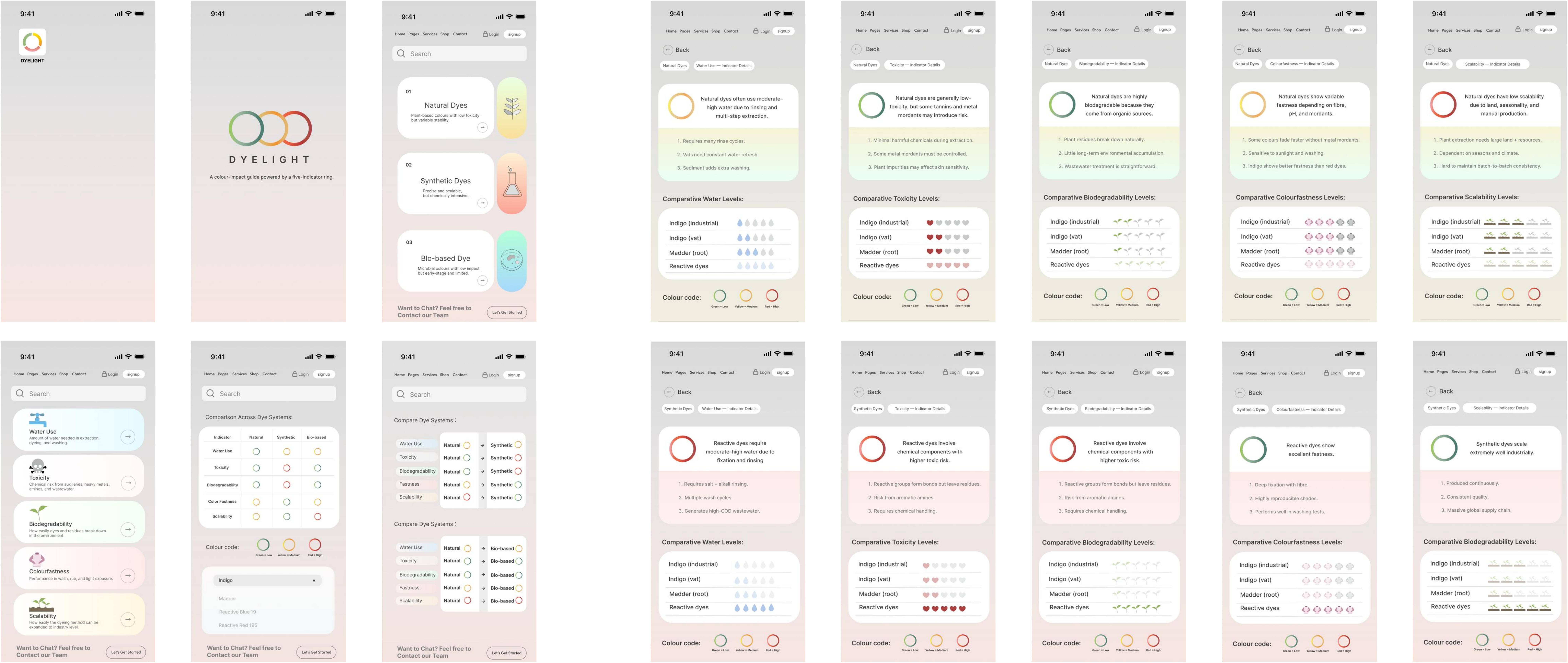
- A designer-friendly framework integrating color fastness data and sustainability indicators (water, toxicity, biodegradability, scalability).

Sustainability Indicator	Indigo	Madder	Reactive Blue 19	Reactive Red 195	Notes
Water Use	🟢	🟡	🟡	🟡	Indigo uses little water, while synthetics need multiple rinses.
Toxicity	🟢	🟢	🔴	🔴	Natural dyes are low-toxic, but synthetics contain reactive salts.
Biodegradability	🟢	🟢	🔴	🔴	Indigo and madder break down easily, unlike persistent synthetics.
Color Fastness	🟡	🟡	🟢	🟢	Synthetics stay stable; Naturals fade slightly but remain usable.
Scalability	🟡	🔴	🟢	🟢	Indigo scales through powder or fermentation, while synthetics scale easily.

🟢 Excellent / Recommended 🟡 Acceptable / Use with caution 🔴 Poor / Not recommended

DYELIGHT — Mock-up Overview

- A multi-platform interface mock-up showcasing dye comparison, indicators, and interaction pathways.



The findings were translated into a digital tool that helps designers compare dyes across five sustainability indicators.

Figures 197. Mock up. Designed by author.

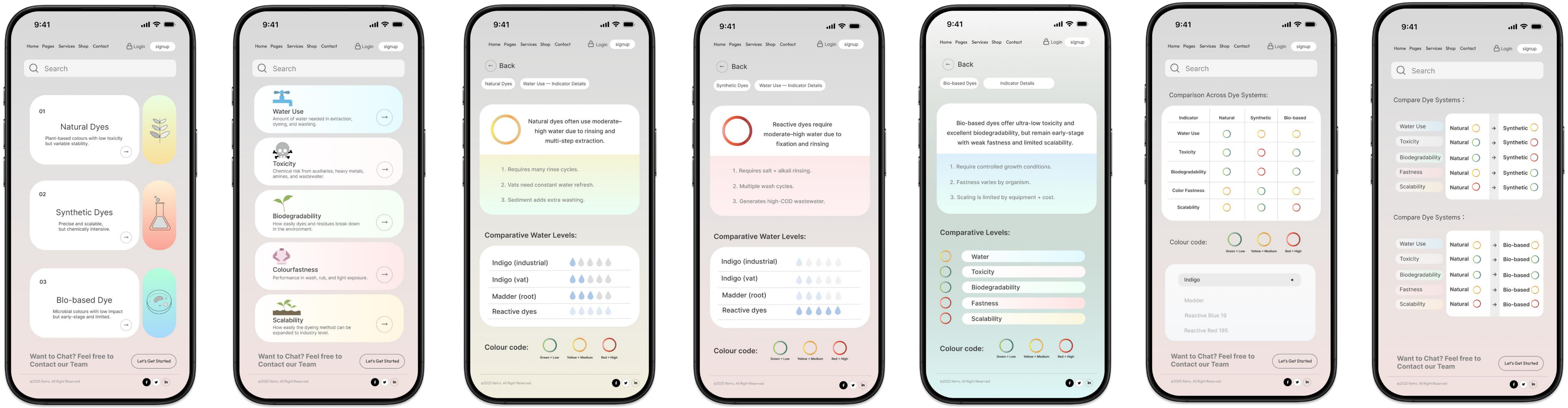
Mobile Interface — Dye System

- **Key screens demonstrating mobile interaction flow.**

This mobile mock-up visualizes a simple and intuitive dye-evaluation interface for designers.

It demonstrates:

• Three dye categories
• Five sustainability indicators
• Comparison logic
• Colour-coded impact scoring system

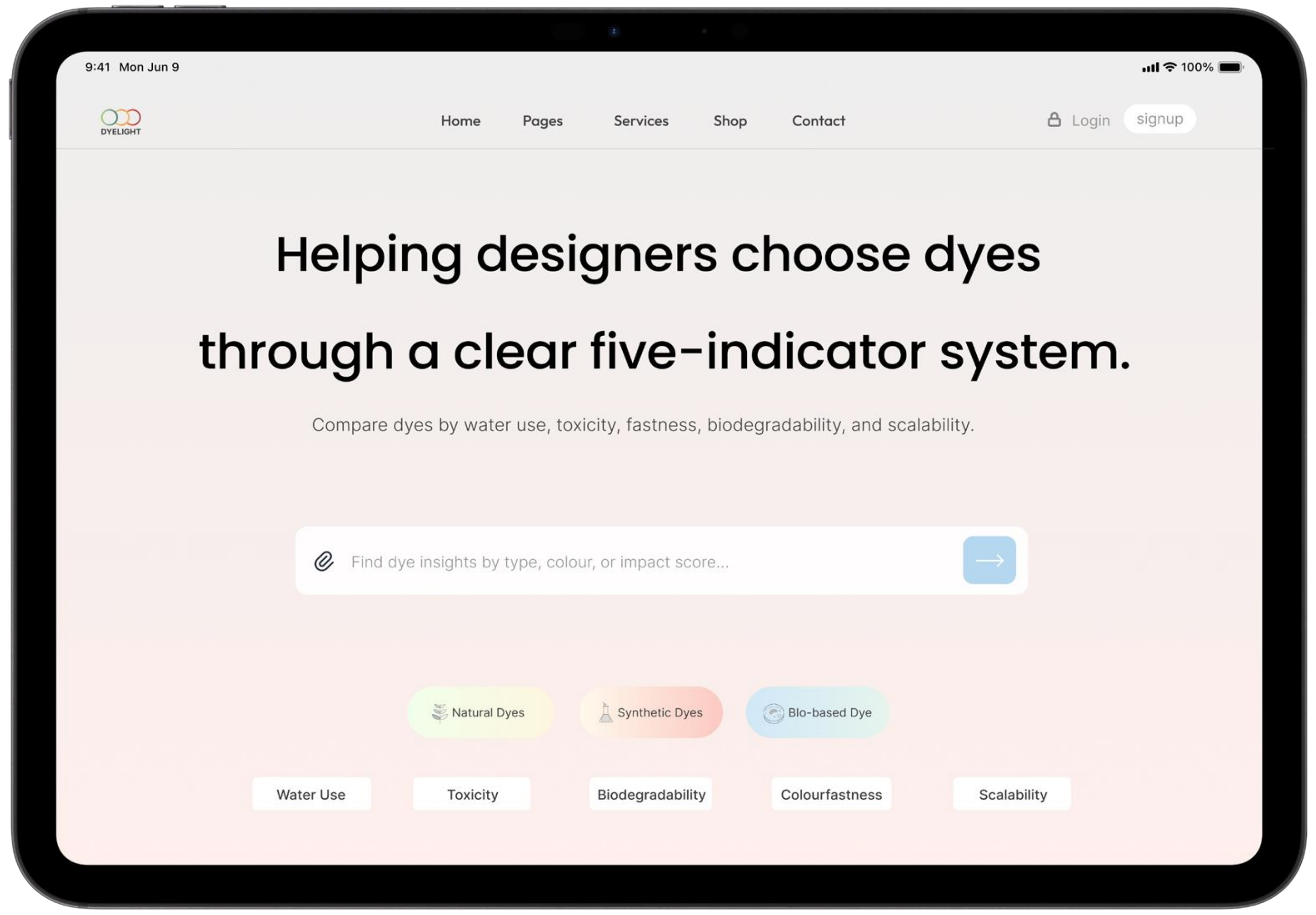


Figures 198. Mobile Mock up. Designed by author.

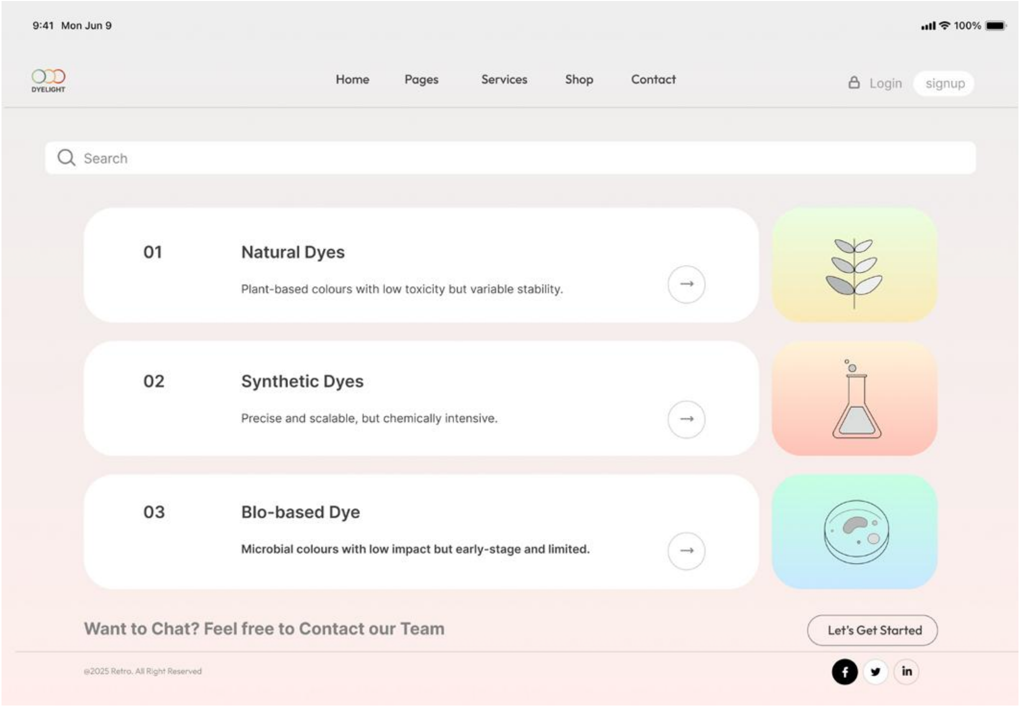
Web Interface — Expanded

- Large-screen layout for deeper comparison and clearer data display.

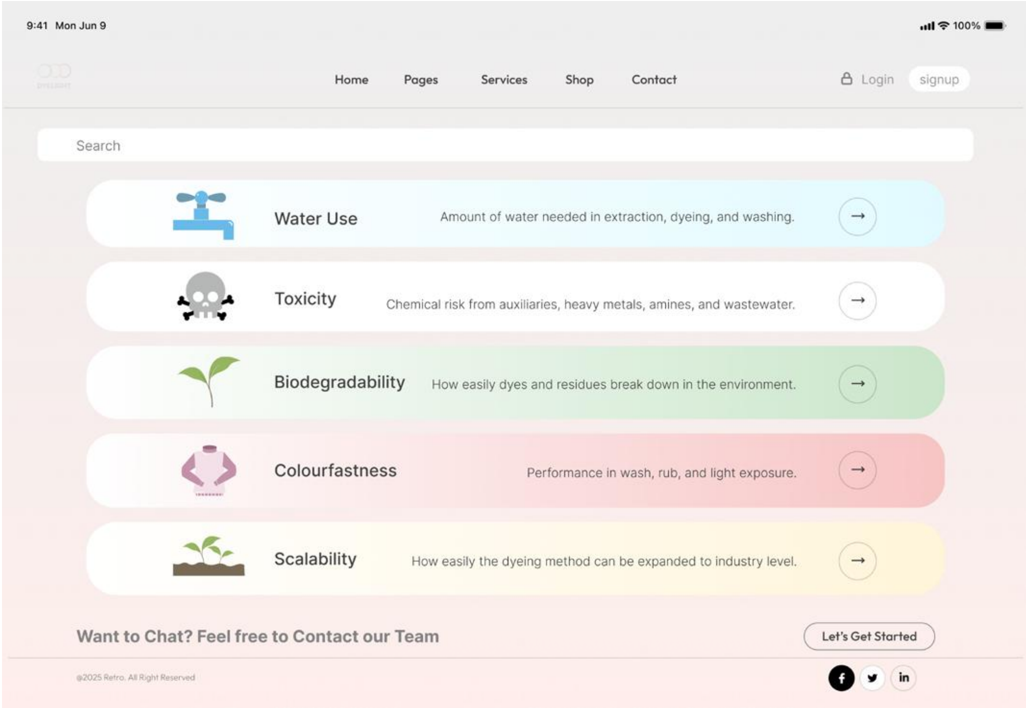
Web Landing page



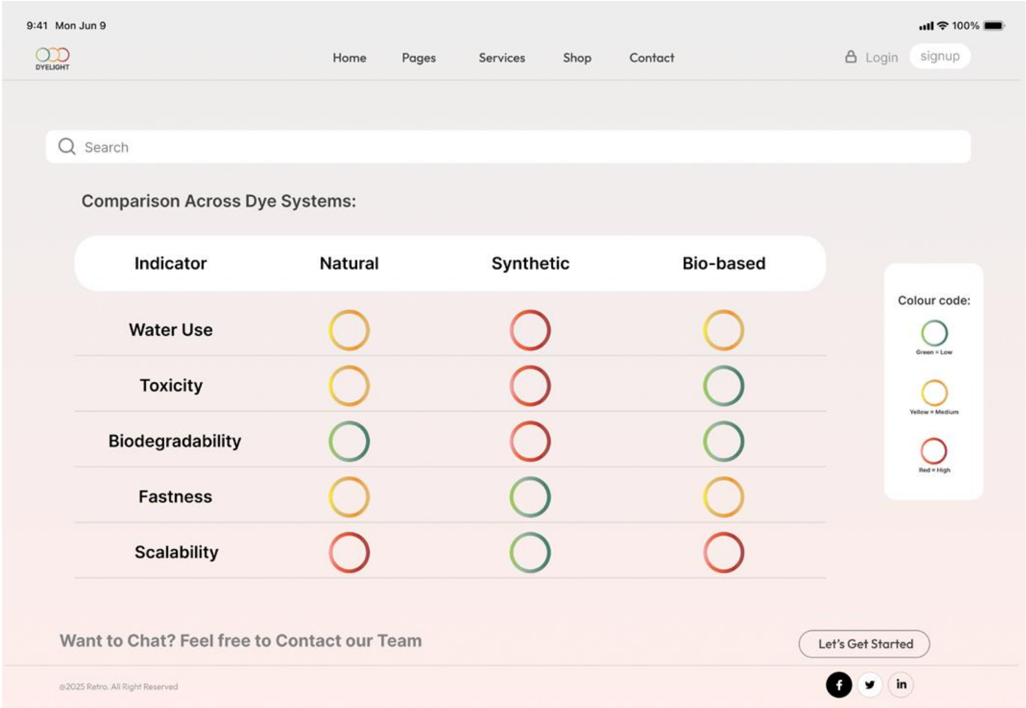
Dye Categories



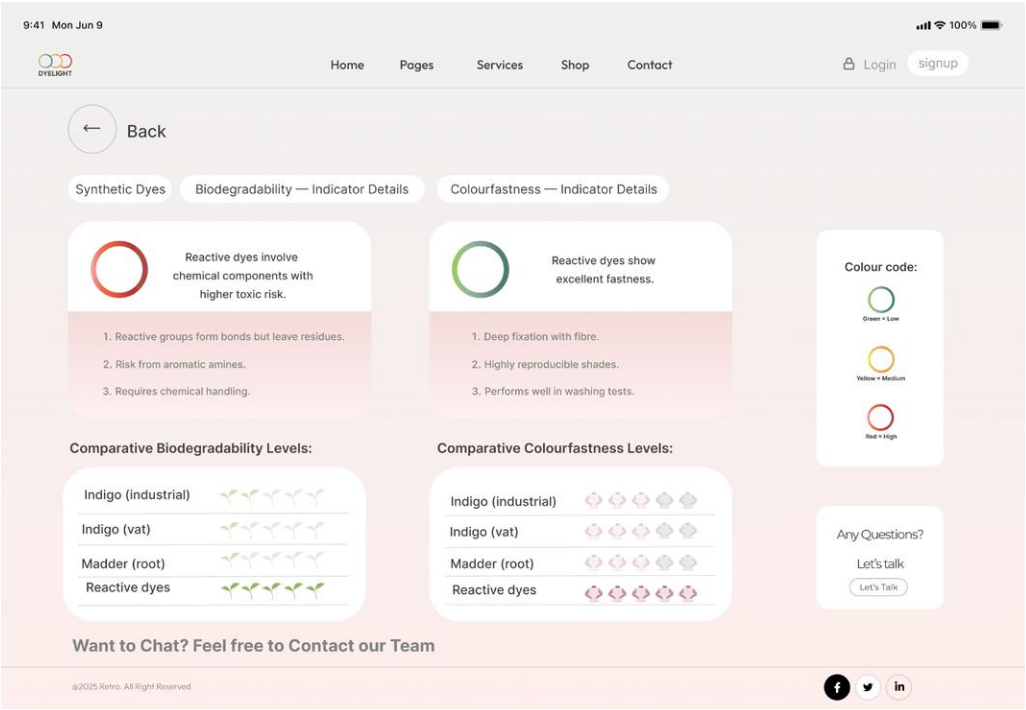
Indicators Overview



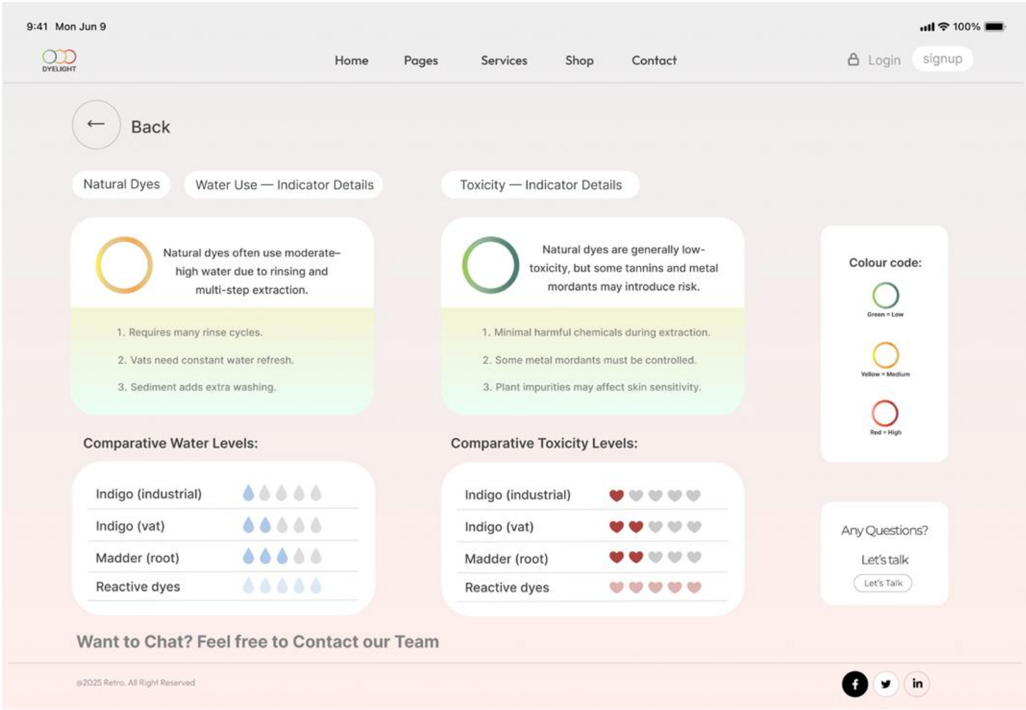
Comparison Table



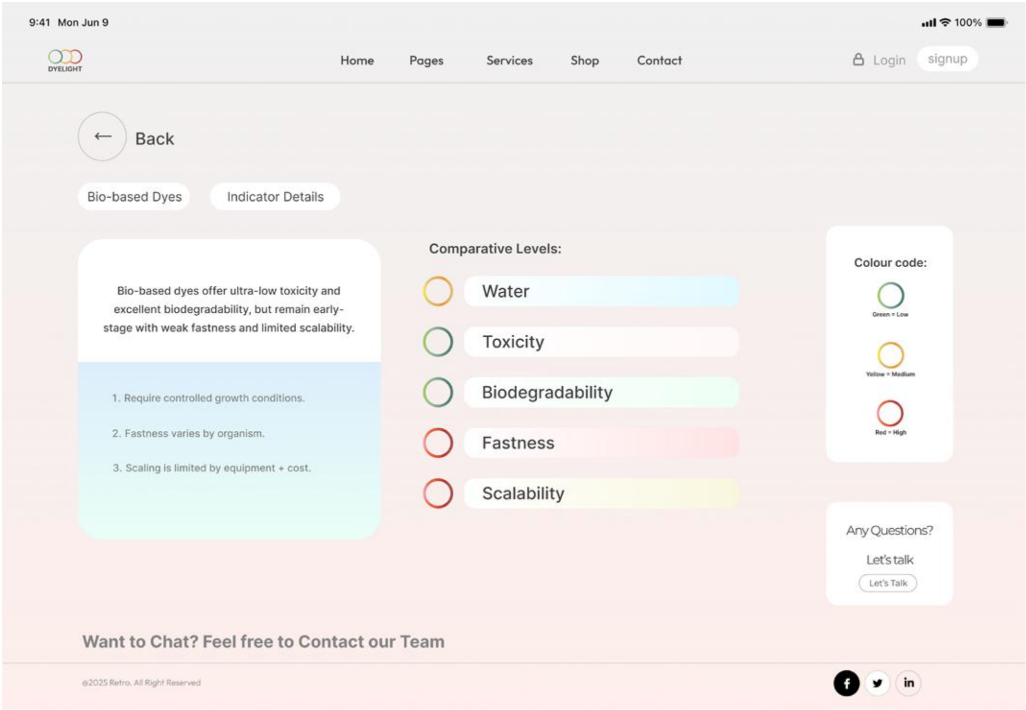
Indicator Details - Synthetic dyes



Indicator Details - Natural dyes



Indicator Details - Bio-based dyes



Figures 198. Web Interface. Designed by author.

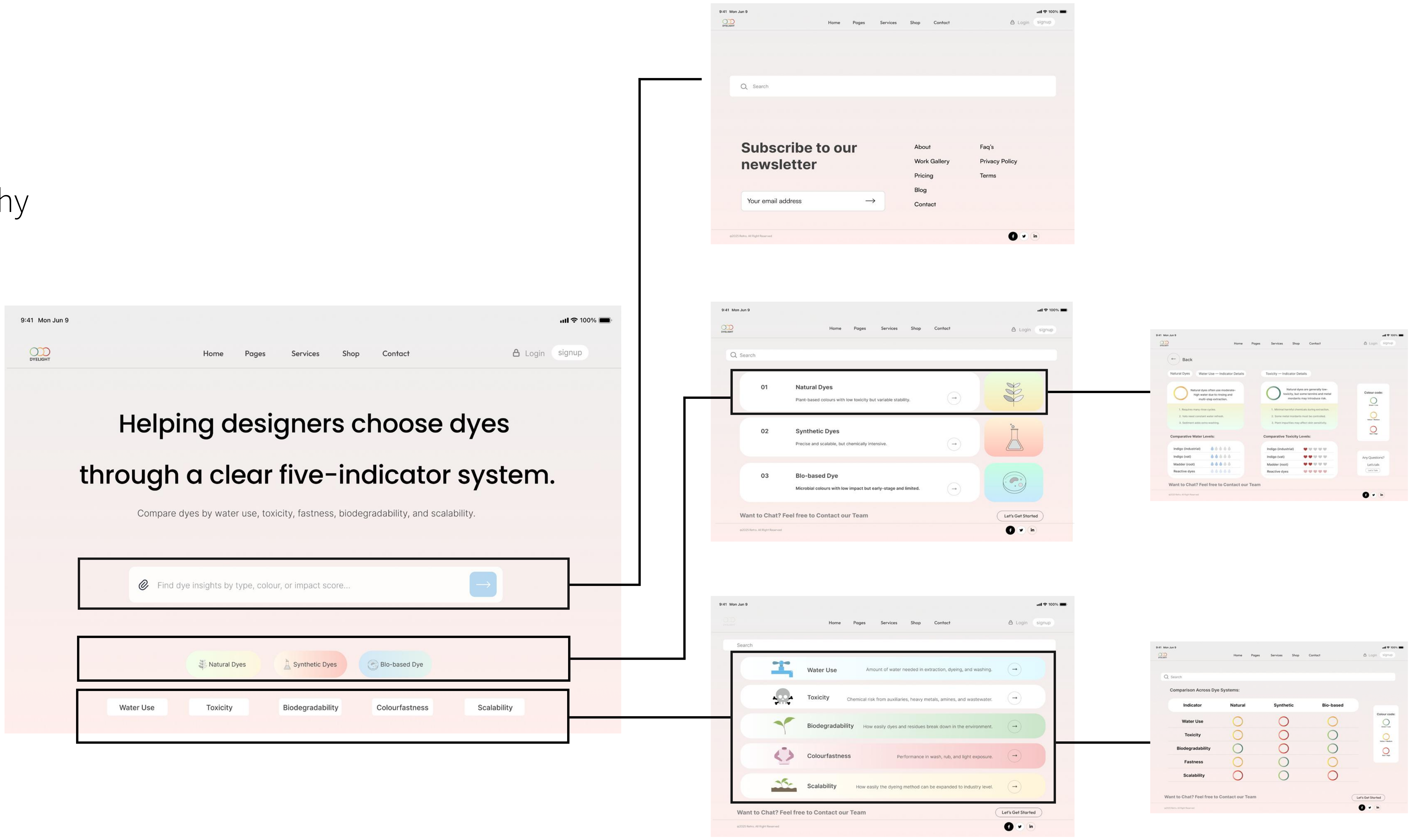
Interactive Prototype

- Motion click-through prototype + QR code

The motion mock-up highlights:

- Simple click-through navigation
- Category → Indicator transitions
- Comparison table linking
- Basic motion cues for UI hierarchy

Scan to explore the interactive demo



Extension | Future BioDye Systems

- From dye libraries to bio-driven color innovation: early directions and future potentials.

While this project focuses on natural and synthetic dyes, the wider dyeing landscape is shifting toward bio-driven colour systems. Insights from my earlier BioData research—covering microbial pigments and slime-mould based pattern generation—reveal how biological processes can expand the vocabulary of colour beyond plant or petrochemical sources.

Current microbial dye research demonstrates three advantages:

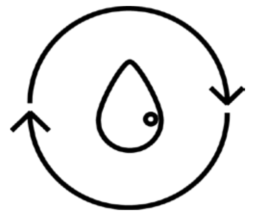
	Circularity	pigments produced from renewable organisms rather than mined or cultivated resources.
	Low-energy processing	colors generated at ambient temperatures with minimal water.
	Programmability	The possibility of tuning colour intensity or hue through nutrients, growth conditions, or genetic modification.

Figure 197. Icons designed by author.

Although still experimental, these systems offer a complementary pathway to the dye library developed in this project. Future extensions may explore how bio-dyes could be integrated into the same traffic-light evaluation framework, or how designers can combine biological and artisanal processes to build hybrid sustainable dye practices.

Conclusion

A system bridging sustainable dye data and designer decision-making

This project developed a designer-facing dye library and a five-indicator traffic-light system that translates complex dye data into accessible visual guidance.
By integrating standards, fieldwork, and laboratory testing, it demonstrates how sustainable colour selection can be embedded into fashion workflows.
Future work may expand the library and integrate emerging bio-based dye systems into the same framework.

End of Project Portfolio

References

Astute Analytica (n.d.) Textile dyes market. Available at: https://www.astuteanalytica.com/industry-report/textile-dyes-market (Accessed: 15 November 2025).

Devi Priya, M. & Siril, E.A. (2022) 'Effect of mordants and mordanting methods on the dyeing property of anthraquinone based dye from Rubia cordifolia', Discovery, 58(319), pp. 742–749.

Environmental Audit Committee (2019) Fixing fashion: clothing consumption and sustainability – Sixteenth Report of Session 2017-19. Available at: https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/1952/full-report.html (Accessed: 15 November 2025).

European Parliament (2020) Fast fashion: EU laws for sustainable textile consumption. Available at:https://www.europarl.europa.eu/topics/en/article/20201208STO93327/fast-fashion-eu-laws-for-sustainable-textile-consumption (Accessed: 15 November 2025).

European Chemicals Agency (ECHA) (n.d.) REACH Regulation. Available at: https://echa.europa.eu/regulations/reach (Accessed: 15 November 2025).

Global Growth Insights (n.d.) Dyes market report. Available at: https://www.globalgrowthinsights.com/market-reports/dyes-market-106654 (Accessed: 15 November 2025).

Global Standard gGmbH (2020) GOTS Version 6.0 Manual. Available at: https://global-standard.org/images/resource-library/documents/standard-and-manual/GOTS_Version_6.0_Manual_EN_CN.pdf

Good On You (n.d.) Is Indigo Dye Sustainable?. Available at: https://goodonyou.eco/is-indigo-dye-sustainable/ (Accessed: 15 November 2025).

Haji, A. (2012) 'Study the effect of metal ion on wool fabric dyeing with tea as natural dye', Research Journal of Chemical Sciences, 2(6), pp. 8–13. Available at: https://www.researchgate.net/publication/232410323_Study_the_effect_of_metal_ion_on_wool_fabric_dyeing_with_tea_as_natural_dye (Accessed: 15 November 2025).

Institute of Public & Environmental Affairs (IPE) (n.d.) Pollution Map — Water Function Zones. Available at: https://wwwen.ipe.org.cn/MapWater/WaterFunction.aspx?q=2&type=0 (Accessed: 15 November 2025).

iPlant.cn (n.d.) Rubia tinctorum. Available at: https://www.iplant.cn/bk/3D27B044B1B96E54 (Accessed: 15 November 2025).

References

Lara, L.R., Cabral, I.M., & Cunha, J. (2022) Ecological Approaches to Textile Dyeing: A Review. Sustainability, 14(14), 8353. Available at: https://www.mdpi.com/2071-1050/14/14/8353 (Accessed: 15 November 2025).

MedChemExpress (n.d.) Rubia cordifolia L. Available at: https://www.medchemexpress.cn/NaturalProducts/rubia-cordifolia-l.html (Accessed: 15 November 2025).

MedChemExpress (n.d.) Indigo. Available at: https://www.medchemexpress.cn/Indigo.html (Accessed: 15 November 2025).

National Center for Biotechnology Information (NCBI) (n.d.) Rubia tinctorum. Available at: https://www.ncbi.nlm.nih.gov/books/NBK326613/ (Accessed: 15 November 2025).

OEKO-TEX® Association (2021) OEKO-TEX STANDARD 100 – Standard. Available at: https://www.oeko-tex.com/fileadmin/user_upload/Marketing_Materialien/STANDARD_100/Standard/OEKO-TEX_STANDARD100_Standard_EN.pdf

TESTEX (n.d.) About TESTEX. Available at: https://www.testex.com (Accessed: 15 November 2025).

World Dye Variety (n.d.) Reactive Red 195. Available at: https://www.worlddyevariety.com/reactive-dyes/reactive-red-195.html (Accessed: 15 November 2025).

World Dye Variety (n.d.) Reactive Blue 19. Available at: https://www.worlddyevariety.com/reactive-dyes/reactive-blue-19.html (Accessed: 15 November 2025).

Wicker, A. (2025) A Reference for Water Consumption During Indigo Dyeing. Transformers Foundation.