



TRADITIONAL TEXTILE DYEING TECHNIQUES AS SUSTAINABLE SOLUTION IN CONTEMPORARY DESIGN

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Abstract: *The study analyzes the potential of traditional textile dyeing techniques as a resource for sustainability and as a pedagogical instrument in contemporary design, based on experimental protocols and textile samples developed within a scientific and educational context. The empirical material highlights a chromatic palette constructed through local or accessible plant-based sources, simple extraction methods, and variable fixation processes, revealing visible differences between natural and synthetic substrates.*

The experiments revealed significant differences between natural and synthetic textile substrates, with natural fibers showing superior dye absorption and color stability. The use of different mordants influenced both chromatic intensity and tonal variation: acetic acid preserved warmer shades, while iron-based mordants generated darker grey and khaki tones. The resulting palette demonstrated a wide diversity of organic colors and confirmed the potential of natural dyeing techniques for sustainable and educational applications in contemporary textile design.

The article interprets these results in relation to current frameworks concerning circularity and textile wet processing, arguing that the sustainable relevance of traditional techniques depends not only on the source of the dye, but also on process control, impact reduction, and the capacity to design for durability.

The proposed approach is interdisciplinary, situated at the intersection of design and heritage, aiming to

Key words: *textile design; fashion design; textile heritage; natural dyeing; color; interdisciplinarity.*

1. INTRODUCTION

In the current context of contemporary design, marked by ecological imperatives and the need to redefine the relationship between production and consumption, traditional textile practices are regaining attention in research as active resources for sustainable innovation [1]. Increasing concerns regarding pollution generated by textile wet processing, excessive water consumption, and the short life cycle of fashion products have encouraged designers and researchers to explore alternative methods based on local resources, circularity, and material responsibility.

Within the present design paradigm, heritage is no longer perceived as a static formal repertoire, but rather as an open system of meanings, susceptible to reinterpretation. In this framework, traditional dyeing techniques are understood not only as utilitarian procedures, but also as forms of accumulated material intelligence, reflecting the direct relationship between humans, the environment, and resources [2], [7]. The integration of these practices into contemporary design implies a shift in emphasis: from product to process; from standardization to variability; from absolute control to co-creation with the



material. Thus, color obtained through natural dyeing functions both as an aesthetic attribute and as the result of a dialogue between material, time, and human intervention, shaping an aesthetic of controlled imperfection and authenticity.

At the same time, current approaches to sustainable textile design increasingly emphasize interdisciplinarity, practice-based research, and the educational dimension of material experimentation. Traditional dyeing techniques are therefore reconsidered not only as historical craft practices, but also as instruments for developing ecological awareness and alternative creative methodologies within design education [8]. In this context, experimentation becomes both a technical and reflective process, capable of generating new relationships between heritage, innovation, and sustainability.

In this sense, the revitalization of textile heritage involves not only the preservation of historical techniques, but also their critical reinterpretation and integration into contemporary design processes, where materiality, process, and cultural meaning become inseparable. Accordingly, the study proposes an analysis of natural dyeing experiments conducted in a scientific and educational context, based on the use of plant-based dyes, as well as variations in color fixation achieved through accessible means. Beyond its technical dimension, the approach is framed as practice-based artistic research, in which the visual outcome becomes an instrument of knowledge [8].

2. RESEARCH DESIGN AND ANALYTICAL FRAMEWORK

2.1 Experimental approach

The experimental approach was based on the use of accessible plant resources, particularly: oak leaves (both fresh and dried), onion skins, red cabbage, and spontaneous plants (including leaves and vegetal residues). The dyeing processes included thermal extraction (boiling), maceration, two-stage dyeing (boiling and subsequent immersion), and fixation.

An essential aspect highlighted in the working journals is the duration of the processes (ranging from several hours to several days), which directly influences the intensity and stability of the color. Significant differences were also observed between natural and synthetic textile materials, with natural fibers demonstrating a higher capacity for absorption and color fixation. The methodology does not aim to standardize results; on the contrary, it values variation as a design principle. The experimental dyeing tests were carried out on both natural and synthetic textile substrates. The natural fabrics included 100% cotton, linen, and wool samples, while the synthetic category included polyester-based fabrics. The textile samples were selected in order to compare differences in dye absorption, chromatic intensity, and color fastness depending on fiber composition and surface structure.

2.2 Executive Summary

The present analysis brings together experimental data extracted from project protocols (2025–2026) concerning the production of color from plant-based sources (agro-waste, leaves/bark, spices/vegetables), alongside official sources (UNEP, ISO, PLOS; BAT/BREF documentation) [1], in order to formulate a techno-scientific argument: traditional dyeing and botanical printing techniques can reduce chemical risk and support circularity, but only if they are rigorously managed in terms of water and energy use, reproducibility, and effluent control.

From the perspective of the international framework, the issue is both legitimate and highly relevant. United Nations Environment Programme (UNEP) indicates that the transformation of the textile sector depends on three interconnected directions: shifting consumption patterns, improving practices, and investing in infrastructure, while wet processing remains a critical node of environmental impact. A study published in Public Library of Science on 18 textile processing facilities reports an average consumption of 164 L of water and 449 g of chemicals per 1 kg of




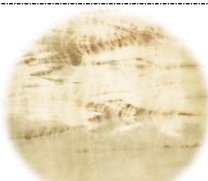



processed material. This explains why even a design-oriented study must address, in a clear and informed manner, the dye bath, energy input, mordants, and effluents, rather than focusing solely on visual outcomes [2].

3. EXPERIMENTAL CORPUS AND DATA SYNTHESIS

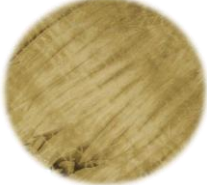
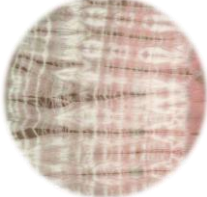

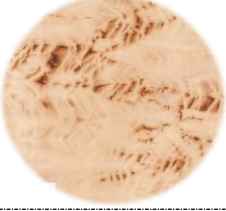

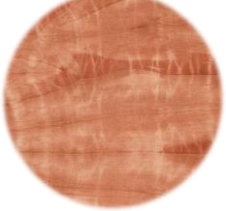

The experimental data consist of protocols derived from practice-based research, and the table below presents a synthetic overview of selected relevant results.

Table 1: *Synthesis of Experimental Results on Textile Dyeing with Natural Colorants*

Source (dye)	Type of raw material	Method	Mordant/fixative	Observations on color and stability	Examples of samples
Red grapes (crushed)	Agro-waste / fruit	Boiling -20 min, + FeSO ₄ (10 g/300 ml H ₂ O)	CH ₃ COOH (6%) (150 ml/1000 ml H ₂ O) Aging – 5 days	Reddish-brown shades (15 samples), stabilize after fixation	
Green quince leaves	Agro-waste/ leaves	Boiling -25 min	FeSO ₄ (10 g/300 ml H ₂ O) Aging – 5 days	Ochre – pale yellow – cappuccino shades (18 samples) stabilize after fixation	
Quince leaves (finely chopped)	Agro-waste /leaves	Boiling - 20 min + 14 hours immersion in the dye bath	CH ₃ COOH (6%) (150 ml/1000 ml H ₂ O) Aging – 5 days	Pink - ochre – cappuccino; (12 samples) on natural samples, the shades remain more intense than on synthetic ones	
Nectarine leaves	Agro-waste /leaves	Boiling - 20 min	CH ₃ COOH (6%) (150 ml/1000 ml H ₂ O) Aging – 5 days	Ochre – cappuccino shades (16 samples) stabilize after fixation	
Pear leaves	Agro-waste /leaves	Boiling -30 min	CH ₃ COOH (6%) (150 ml/1000 ml H ₂ O) Aging – 5 days	Ochre–grey, slightly subdued shades (10 samples), good stability	




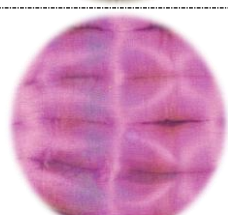
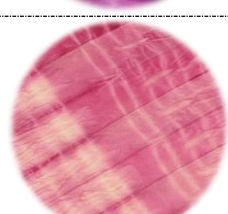
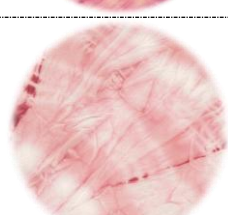
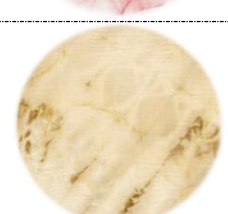


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<i>Oak leaves</i>	<i>Leaves</i>	<i>Boiling -30 min</i>	<i>FeSO₄</i> <i>(10 g/300 ml H₂O)</i> <i>Aging – 5 days</i>	<i>Green–khaki shades</i> <i>(21 samples), very</i> <i>good stability</i>	
<i>Rowan berries</i>	<i>Agro-waste / fruit</i>	<i>Boiling -30 min</i>	<i>Left - FeSO₄</i> <i>(10 g/300 ml H₂O)</i> <i>Right-</i> <i>CH₃COOH (6%)</i> <i>(150 ml/1000 ml</i> <i>H₂O)</i> <i>Aging – 5 days</i>	<i>Left – pink; right –</i> <i>beige-grey (14</i> <i>samples), good</i> <i>stability on natural</i> <i>fibers</i>	
<i>Dried elderberries</i>	<i>Agro-waste / fruit</i>	<i>Boiling - 30 min</i>	<i>FeSO₄</i> <i>(10 g/300 ml H₂O)</i> <i>Aging – 5 days</i>	<i>Grey–beige with a</i> <i>cool undertone (18</i> <i>samples), low stability</i>	
<i>Oak tree bark</i>	<i>Agro-waste</i>	<i>Boiling -35 min</i> <i>+ 14 hours</i> <i>immersion in</i> <i>the dye bath</i>	<i>KOH</i> <i>(100ml/1000 ml H₂O)</i>	<i>Brown–beige shades</i> <i>(13 samples), good</i> <i>stability</i>	
<i>Apple tree bark</i>	<i>Agro-waste</i>	<i>Boiling -35 min</i> <i>+ 14 hours</i> <i>immersion in</i> <i>the dye bath</i>	<i>CH₃COOH (6%)</i> <i>(150 ml/1000 ml</i> <i>H₂O)</i> <i>Aging – 2 days</i>	<i>Ochre–light brown</i> <i>shades (24 samples),</i> <i>very good stability</i>	
<i>Brown onion peels</i>	<i>Agro-waste</i>	<i>Boiling -35 min</i>	<i>CH₃COOH (6%)</i> <i>(150 ml/1000 ml H₂O)</i> <i>Aging – 2 days</i>	<i>Ochre–pink–brown</i> <i>shades (15 samples),</i> <i>very good stability</i>	
<i>Plane tree bark</i>	<i>Agro-waste</i>	<i>Soaking (10</i> <i>hours)</i> <i>Boiling -40</i> <i>min+ 48 hours</i> <i>immersion in</i> <i>the dye bath</i>	<i>FeSO₄</i> <i>(10 g/300 ml H₂O)</i> <i>Aging – 3 days</i>	<i>Ochre–cappuccino</i> <i>and ochre–khaki</i> <i>shades (14 samples),</i> <i>good stability</i>	



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Turmeric	Spices	Boiling - 60 min	CH_3COOH (6%) (150 ml/1000 ml H_2O) Aging - 5 days	Pale yellow-brown shades (8 samples), good stability	
Turmeric	Spices	Dissolution + short heating (5-7 min)	CH_3COOH (6%) (150 ml/1000 ml H_2O) Aging - 1 days	Intense yellow (6 samples) good stability	
Red onion peels	Agro-waste	Boiling -50 min	CH_3COOH (6%) (150 ml/1000 ml H_2O) Aging - 5 days	Ochre-reddish-brown-khaki shades (24 samples), very good stability	
Red cabbage	Agro-waste Vegetable	Boiling -60 min	CH_3COOH (6%) (150 ml/1000 ml H_2O) Aging - 5 days	Purple shades (14 samples), low stability	
Hibiscus flowers	Agro-waste	Boiling -60 min	CH_3COOH (6%) (150 ml/1000 ml H_2O) Aging - 5 days	Burgundy shades (12 samples), good stability	
Beetroot	Agro-waste	Boiling -20 min	CH_3COOH (6%) (150 ml/1000 ml H_2O) Aging - 5 days	Light pink-burgundy shades (13 samples), low stability	
Dried nettle	Leaves	Boiling -40 min	Without fixation Aging - 4 days	Beige-light ochre shades (14 samples), good stability	



The reading of the table suggests several design insights:

- The mordant functions not only as a technical agent, but also as an aesthetic one: acetic acid often preserves warm tones, while iron shifts the palette toward greys, khaki, and muted shades.
- Many observations indicate a perceptible difference between natural and synthetic substrates (textile materials), which transforms fiber selection into a conceptual decision, rather than merely an executional one.
- The series of samples can function as a library of chromatic surfaces, useful in fashion and textile design, particularly for compositional exercises within the educational process [3].

4. SUSTAINABILITY ASSESSMENT BY FEEDSTOCK CATEGORIES

Agro-waste—such as onion skins, coffee grounds, and fruit residues—represents, among all categories, the most easily justifiable option within the logic of the circular economy. It valorizes an already existing waste stream and reduces dependence on raw materials cultivated specifically for dyeing purposes. However, this advantage is maintained only if the process remains measured and controlled: the protocols indicate repeated boiling and distinct fixation stages, which imply water and energy consumption even at a small scale. In this context, comparison with industrial wet processing becomes relevant: when the literature reports averages of 164 L of water/kg and 449 g of chemicals/kg, the design studio should not replicate industrial practices, but rather learn to make its own resource consumption visible through simple indicators [1]

Leaves and bark present a different type of potential: they introduce into the process both pigment and memory. From a technical perspective, many of these sources are rich in compounds that can support color fixation, making them promising for biomordanting solutions as well. At the same time, this category requires careful attention to extraction: experiments show that prolonged boiling (up to one hour) is often necessary. From a forward-looking perspective, there is room for long-duration soaking experiments. In BREF terms, this reflects precisely the logic of a process that must be conceived in relation to resource consumption and emissions, not solely through its visual outcome [4]

Spices and vegetables offer the most visually striking colors, but also exhibit the greatest vulnerability to process variations. Turmeric produces an intense yellow; however, experiments show that the introduction of iron can rapidly desaturate it. Red cabbage is highly sensitive to pH changes and to its interaction with different textile substrates. In this case, sustainability must be addressed not only in terms of natural origin, but also in relation to the durability of the aesthetic effect: an unstable color reduces the product's lifespan and may undermine the very principle of responsible consumption. The United Nations Environment Programme report emphasizes precisely those practices that enhance circularity and extend the lifespan of materials [1].

Across all three categories, chemicals remain the critical point. The protocols include acetic acid, lye, and iron salts. For iron sulfate, the European Chemicals Agency indicates in its substance information that notifications under REACH Regulation identify it as harmful to aquatic life with long-lasting effects. This does not preclude its use in workshop settings, but it does require discipline: minimal dosing, separate collection, neutralization, and the avoidance of uncontrolled discharge [5].

The comparison with industry must be approached with caution. A textile design laboratory cannot—and should not—compete with an industrial facility; however, an analogy based on Life Cycle Assessment is useful. International Organization for Standardization defines, through ISO 14040 and ISO 14044, the framework for life cycle assessment: goal and scope, system boundaries, inventory analysis, impact assessment, and interpretation. For the proposed experiments, a simplified LCA is sufficient [6].



At the industrial level, the BREF document for textiles developed by the Joint Research Centre of the European Commission explicitly states that the scope covers pre-treatment processes such as washing, bleaching, mercerization, and the dyeing of fibers and textiles. This reference does not alter the nature of the experiment, but it provides it with a mature framework, as the project operates at an educational scale within a domain that, at an industrial level, is governed by the logic of Best Available Techniques, resource consumption, and emissions [1].

5. RESULT, INTERPRETATION AND FUTURE TESTING DIRECTIONS

5.1. Results and Visual Interpretation

From a design perspective, the chromatic variations obtained through the experiments represent opportunities for constructing unique visual identities, where each piece becomes non-reproducible.

The analysis of textile samples reveals a rich chromatic palette, characterized by organic hues: tones of yellow, ochre, and cappuccino (onion skins), grey-green and brown shades (oak leaves), as well as variations of purple, grey, and desaturated tones (red cabbage, depending on fixation).

A significant element is the influence of mordants on color: acetic acid preserves warmer and lighter tones, while iron salts generate darker shades, shifting toward grey or khaki.

It was also observed that natural materials produce deeper and more stable colors, whereas synthetic materials result in paler and less durable outcomes.

5.2. Testing Perspectives

One of the most promising perspectives, formulated following experiments with biopigment dyeing, is the gradual transition toward biomordants. A recent review on biomordants indicates that natural materials can reduce dependence on chemical mordanting while supporting color fastness without eliminating technical control. In the present project's experiments, leaves and bark rich in tannin compounds prove to be valuable resources for this stage, especially when combined with the agro-waste materials already tested [7, 9].

Another direction concerns the optimization of extraction processes. Recent literature shows that ultrasound and microwave-assisted extraction can shorten processing time and reduce energy consumption; where such equipment is not available, controlled maceration followed by short heating can achieve similar results.

The experimental results support the idea that traditional dyeing techniques can contribute to reducing environmental impact through: the use of local and renewable resources; decreased reliance on synthetic dyes; and the reduction of pollution associated with industrial processes. However, the relevance of these practices does not reside exclusively in ecological parameters, but rather in their capacity to redefine the relationship between the designer and the material. Sustainability thus becomes not only a set of technical solutions, but also a cultural and ethical positioning that prioritizes conscious and responsible processes.

The multidisciplinary character of textile research—explicitly articulated through the importance of traditional methods of production, dyeing, and maintenance, as well as the preservation and promotion of textile art and the integration of results into the educational process—is essential for the development of an ecological direction and the promotion of responsible and sustainable consumption. In this study, interdisciplinarity is not merely declarative; it becomes a method, supported by sample sheets, metadata, and minimal testing protocols. Traditional dyeing is not only a practice, but also a design principle: materials are conceived to evolve over time, while patina and tonal shifts become part of the product's identity.

The role of small-scale, university-based workshops, for instance, can be understood as a contemporary laboratory of living heritage, capable of producing prototypes, micro-collections, and



educational resources. In this way, the training of the contemporary designer shapes the educational dimension of the study. The involvement of students in such experiments fosters: the development of sensitivity toward materials; the understanding of processes, not only outcomes; and the acceptance of variability as an integral part of the creative process. In this context, the workshop becomes a space of research, and experimentation—an essential pedagogical instrument. Students not only reproduce techniques, but also learn to observe, interpret, and integrate results into their own design language. This approach contributes to shaping a generation of designers who operate not solely within the logic of production, but increasingly within that of cultural and ecological responsibility [8].

5. CONCLUSIONS

The experimental results demonstrate that traditional dyeing techniques can support a credible discourse on sustainability only when they are approached simultaneously as heritage, as a design method, and as a responsible practice. Plant-based material alone does not guarantee sustainability; rather, it is the manner in which it is extracted, fixed, measured, and integrated into a culture of durable use that defines its relevance. This also represents the core pedagogical stake—the formation of designers who understand color not merely as an effect, but as a relationship between resource, process, and the subsequent life of the object.

The integration of these practices into design education contributes to the development of an interdisciplinary perspective, in which heritage, materiality, and innovation coexist. In this way, sustainability becomes a form of design culture, constructed through experience, reflection, and responsibility.

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