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Design Of A Low-Water Natural Dyeing Protocol for Graded Tonal Series Using Onion Skin, Pomegranate Rind and Walnut Hull

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ABSTRACT
This paper examines the development of a low-water natural dyeing protocol for creating graded tonal series on 100% cotton fabric using three plant-derived materials: onion skin, pomegranate rind and walnut hull. The study is positioned within sustainable textile and fashion design, with particular attention to the use of food-related plant residues, controlled colour development and careful accounting of water used during wet processing. Rather than treating natural colourants as automatically sustainable, the research considers the practical relationship between raw-material preparation, extraction, mordanting, dye application, rinsing, colour consistency and resource use. The proposed approach uses a documented cotton substrate, measured material quantities, controlled liquor ratios and repeatable processing conditions. Fitkari (alum) is identified in the thesis as the principal mordant condition, while pomegranate rind is also considered for its tannin-rich composition and possible role in plant-based treatment. A graded tonal series is intended to be developed by varying defined process parameters such as extract concentration or dye-bath strength while keeping other conditions consistent. The paper also discusses PeelCascade as a proposed water-routing concept in which selected process streams may be directed to earlier stages. This concept requires separate testing and is not presented as a validated water-saving system. The available thesis material does not provide a complete verified dataset of colour measurements, fastness ratings or water savings; therefore, the paper presents the research framework, design direction and testing requirements without claiming unverified experimental outcomes.

Keywords: natural dyeing; low-water textile processing; onion skin; pomegranate rind; walnut hull; cotton; graded tonal series; fitkari; sustainable fashion.

1. INTRODUCTION
Textile colour is an important part of fashion design because it influences the visual identity, mood and perceived value of a fabric or finished product. Dyeing is not only a colour-making activity; it is also a wet-processing operation involving material preparation, extraction or dissolution, application, rinsing and finishing. Each stage can require water, energy, time and auxiliary

materials. For this reason, the development of a responsible dyeing process must consider both the appearance of the final textile and the resources required to produce it.

Natural dyes obtained from plants have renewed relevance in contemporary textile research. They connect material exploration with traditional knowledge, renewable biological sources and the possible reuse of food-processing residues. Onion skins and pomegranate rinds are often discarded after food preparation, while walnut hulls are a recognised source of brown-toned colourants. Their use may offer an opportunity to convert residual biomass into a useful textile resource. However, natural origin alone does not establish environmental superiority. Extraction may require heating and water, shades may vary between batches, and poor fastness may reduce the useful life of a dyed product.

The present research focuses on a low-water dyeing protocol for graded tonal series on cotton using onion skin, pomegranate rind and walnut hull. A graded tonal series refers to a planned progression of related shades developed through controlled changes in dye concentration or application conditions. The intention is to create a usable palette while maintaining consistency in fabric preparation, bath conditions and documentation. Cotton is selected because it is widely used in apparel and home textiles and provides a relevant cellulosic substrate for fashion-design applications.

A further concern is the accurate measurement of water consumption. Water is used not only in the dye bath but also during fabric scouring, plant extraction, mordant preparation, rinsing and equipment cleaning. Measuring only the final dye bath would understate the total process demand. The study therefore proposes stage-wise water accounting and considers PeelCascade as a separate concept for routing selected water streams to earlier process stages after suitability has been assessed.

2. AIM AND RESEARCH OBJECTIVES

The aim of this study is to develop and examine a low-water natural dyeing protocol for producing graded tonal series on 100% cotton fabric using onion skin, pomegranate rind and walnut hull, while considering colour development, process repeatability, fastness and resource use.

- To study the dyeing potential of onion skin, pomegranate rind and walnut hull on cotton fabric.
- To establish a controlled preparation and dye-extraction approach using documented material quantities and process conditions.
- To explore graded tonal development through controlled variation in dye-bath concentration or application strength.
- To examine the role of fitkari (alum) as the principal mordant condition and distinguish mordanted samples from untreated controls.
- To record water use across fabric preparation, extraction, mordanting, dyeing, rinsing and cleaning stages.
- To identify the testing required to evaluate shade uniformity, colour strength and wash, rubbing and light fastness.

- To translate the resulting natural colour palette into a fashion-design and textile application concept.

3. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

3.1 Natural Colourants and Sustainable Textile Design

Natural colourants are obtained from biological sources and include chemically diverse compounds. Plant-based colourants may contain flavonoids, tannins, phenolic compounds and other pigments. Their behaviour depends on the source species, plant part, maturity, storage, extraction conditions, pH, temperature and fibre substrate. Reviews of natural dyeing identify shade variability and fastness as continuing technical challenges. These challenges make process standardisation essential when natural colourants are considered for repeatable textile production. In sustainable fashion, the value of a material must be considered across its useful life. A dye source may be renewable or derived from waste, but the complete process also involves collection, sorting, drying, extraction, heating, rinsing and disposal. A meaningful evaluation should therefore consider material sourcing, water and energy demand, durability and the intended product use.

3.2 Onion Skin as a Colourant

Dry outer onion skins, particularly those from common onion (Allium cepa), are widely discussed as plant-waste colourant material. Onion skins contain flavonoid compounds, including quercetin, which are associated with yellow, orange and reddish-brown colour development under different processing conditions. The final shade is influenced by the onion variety, peel colour, extraction conditions, mordant and cotton preparation. Onion skin is relevant to this study because it is commonly available as a household or food-processing residue and can be collected separately from other organic waste.

3.3 Pomegranate Rind and Tannin-Rich Compounds

Pomegranate rind contains polyphenolic compounds, including tannins and ellagitannin-related constituents. These compounds are relevant to natural dyeing because they can contribute to colour formation and may interact with metal ions used in mordanting. Pomegranate peel is also of interest as a possible plant-based treatment material. Rahman, Koh and Hong (2024) investigated cotton dyeing using pomegranate rind and onion peel extracts with chitosan as a biomordant, while Botteri, Miljković and Glogar (2022) examined the influence of cotton pre-treatment on dyeing with onion and pomegranate peel extracts. These studies demonstrate the importance of fibre preparation and treatment sequence, but their reported results cannot be assumed to apply directly to the present protocol.

3.4 Walnut Hull as a Brown Colour Source

Walnut-derived dye material must be identified precisely because hull, shell and leaf are not interchangeable. The outer hull or husk is commonly investigated for brown colourants, including juglone-related compounds and tannins. The present study specifies walnut hull as the intended source. Its species, condition, fresh or dried state and preparation method should be recorded so

that the material can be identified and the procedure repeated. Handling should be organised to avoid unintended staining and cross-contamination.

3.5 Cotton Preparation, Mordanting and Fastness

Cotton consists predominantly of cellulose and contains hydroxyl groups that contribute to its absorbency. Natural oils, waxes, pectins, residual sizing and manufacturing finishes may interfere with wetting and dye uptake. Scouring is therefore important for preparing a consistent substrate. All samples should receive the same pre-treatment, and any additional bleaching or finishing should be standardised or excluded from the comparison.

Fitkari commonly refers to alum, often potassium aluminium sulfate, although the commercial product should be checked before use. Alum may influence dye–fibre interaction and shade, but it is not a universal fixer and does not guarantee durability for every plant colourant. The amount should be calculated in relation to dry fabric mass and reported as percentage on weight of fabric. Colour appearance, wash fastness, rubbing fastness and light fastness are separate quality dimensions. Relevant methods include ISO 105-C06 for laundering, ISO 105-X12 for rubbing and ISO 105-B02 for light fastness, subject to laboratory access.

3.6 Low-Water Processing and Research Gap

Water can be consumed during scouring, extraction, mordanting, dyeing, rinsing and cleaning. The amount depends on fabric mass, liquor ratio, shade depth, extraction method and number of rinses. A low-water approach must therefore optimise the full sequence rather than reduce water in one isolated bath. Water reuse may reduce fresh-water demand, but reused streams can contain residual colourants, dissolved plant compounds, salts and mordant residues. Their effect on pH, shade, levelness and fastness must be tested.

Existing research addresses natural colourants, plant-waste dyeing, mordanting and reuse of residual dye baths. The research opportunity in this project is to bring these concerns together in a fashion-design-oriented protocol focused on graded tonal development from onion skin, pomegranate rind and walnut hull on cotton, with stage-wise water accounting. The contribution is a defined comparative and design framework, not a claim that these dye sources or water-reuse principles are newly invented.

4. RESEARCH METHODOLOGY

4.1 Research Design

The study follows an exploratory, experimental and design-based approach. It combines a review of relevant literature with the preparation of cotton samples, plant-dye extraction, controlled dye application, observation of colour development and translation of the resulting palette into a design concept. Pilot trials are required to establish workable extraction and dyeing conditions before the main comparison. The protocol should be documented so that each sample can be traced to its source material and processing conditions.

4.2 Materials and Substrate

The principal materials are 100% cotton fabric from one documented lot, onion outer skins, pomegranate rind, walnut hull, identified fitkari/alum, clean water and the equipment required for weighing, heating, filtering, dyeing, rinsing and drying. Plant material should be identified by source and plant part, and its condition should be recorded as fresh, air-dried or otherwise prepared. The dry mass of each cotton swatch and the mass of plant material should be recorded. Where used, salt should be treated as a separate auxiliary condition and not assumed to perform the same function as alum.

4.3 Cotton Pre-Treatment and Sample Preparation

Cotton should be cut into equal-sized swatches and weighed after conditioning. A consistent scouring procedure should be applied to all samples to remove impurities that may affect wetting and colour uptake. The fabric should be rinsed and dried under consistent conditions. Each swatch should receive a unique code identifying the dye source, treatment condition, tonal level and replicate. Unmordanted controls should be included where feasible to distinguish the effect of the dye extract from the effect of the mordant.

4.4 Preparation of Natural Dye Extracts

Separate extraction batches should be prepared for onion skin, pomegranate rind and walnut hull. Each batch should use a measured mass of plant material and a recorded volume of water. The extraction temperature, duration, vessel, material-to-water ratio, filtration method and final extract volume should be documented. Pilot trials should be used to determine workable conditions for each material because the three sources may not respond equally to one common extraction setting. The selected procedure should then remain consistent across the main comparison.

4.5 Development of the Graded Tonal Series

The tonal series should be produced by defining a small number of extract-strength levels, for example by varying the concentration of filtered extract or the proportion of stock extract in the dye bath. The exact levels should be finalised through pilot trials and recorded numerically. Fabric mass, bath volume, temperature, treatment time, agitation and rinsing should remain constant wherever the design permits. This approach allows the shade progression to be associated with a defined process change rather than several uncontrolled differences. Separate series should be developed for each of the three dye sources.

4.6 Mordanting and Dye Application

Fitkari should be identified from its product label and applied at a defined percentage on weight of fabric. The selected sequence—pre-mordanting, simultaneous mordanting or post-mordanting—should be established during pilot work and maintained for the main comparison. A no-mordant control should be retained where possible. Dyeing should be carried out using recorded bath conditions, with the fabric moved consistently to support even exposure. After dyeing, samples should be rinsed using a measured volume of water, dried away from direct contamination and conditioned before assessment.

4.7 Water Accounting and PeelCascade Proposal

Water use should be recorded separately for scouring, dye extraction, mordanting, dyeing, rinsing and equipment cleaning. The total fresh-water input should be calculated by adding the measured volumes used at each stage. If water is reused, the source, volume, storage duration, treatment and destination stage should be recorded separately. PeelCascade is considered a proposed water-routing concept in which cleaner streams may be reserved for later rinsing and more coloured residual streams may be directed to earlier stages. It is a separate experimental strand and should not be treated as a proven method until repeated trials demonstrate acceptable shade, levelness, fastness and process hygiene.

4.8 Evaluation and Data Analysis

The samples should be assessed under consistent lighting and against a common reference. Visual records should describe hue, depth, tonal progression, levelness and visible defects. If a spectrophotometer or colourimeter is available, instrumental colour values and colour difference may be recorded. Wash, rubbing and light fastness should be tested using appropriate laboratory methods where facilities permit. Resource records should include water, energy estimate, material quantity, process time and approximate cost. Results should be reported only when actual measurements are available; expected colour families or planned procedures must not be presented as measured findings.

5. Design Development And Textile Application

The design-development stage connects the experimental textile work with a fashion-design outcome. A mood board can establish the visual direction through botanical forms, natural surfaces, plant textures and earthy colour references. An inspiration board can translate the layered structure of onion skin, the textured surface of pomegranate rind and the organic character of walnut hull into pattern, colour and surface ideas.

The design sheet should bring together the selected tonal palette, fabric references, sketches, construction details and possible product applications. Physical dyed cotton swatches should guide colour decisions rather than relying only on digital references. The design development board can document the progression from initial sketches and colour experiments to refined product illustrations and final material selection.

The final textile application should be selected according to the actual properties of the samples. Shade character, uniformity, texture, wash requirements, rubbing and light exposure all influence suitability. A naturally dyed fabric may be appropriate for a limited-edition garment, accessory or textile surface, but the intended use should reflect the performance evidence available. The design should allow the natural colour and surface character to remain visible without making unsupported claims about durability or environmental impact.

6. DISCUSSION

The proposed protocol treats low-water dyeing as a process-wide objective. Reducing water in extraction alone may not lower total consumption if the fabric requires repeated rinsing or if the

dye bath needs to be diluted to achieve levelness. A meaningful comparison therefore needs a clear process boundary and a complete record of water use. The graded tonal approach also introduces a balance between visual variety and repeatability: a designer may value a range of related shades, but each level must be reproducible enough to support a coordinated textile collection.

The three plant materials offer different research opportunities. Onion skin and pomegranate rind connect the project with food-residue valorisation, while walnut hull provides a distinct brown-colour source. Their chemistry and extraction behaviour are not identical, so the study should not assume that one temperature, extraction time or mordant condition will be optimal for all three. Pilot trials are necessary to select workable settings, followed by a controlled comparison using consistent cotton preparation and documented sample masses.

The use of alum should also be evaluated rather than presumed beneficial. A darker initial shade does not necessarily indicate improved retention after washing or exposure to light. For the same reason, colour strength, levelness and fastness should be reported separately. Where laboratory facilities are unavailable, the paper should state that limitation and avoid substituting visual impressions for standardised fastness results.

PeelCascade may provide a future route for reducing fresh-water demand, but water reuse introduces possible changes in pH, residual colour, dissolved compounds and contamination. The concept should be tested separately against a fresh-water baseline, with repeated runs and fabric-quality checks. It should not be merged with the primary dye-source comparison in a way that makes the cause of any change unclear.

The present source material does not contain a complete auditable dataset of instrumental colour values, fastness grades, replicate measurements or verified water savings. Consequently, this paper presents the proposed protocol and design framework rather than a claim of proven performance. The next research stage should insert actual experimental records and revise the interpretation to match the evidence.

7. CONCLUSION

This study sets out a research framework for developing a low-water natural dyeing protocol for graded tonal series on 100% cotton using onion skin, pomegranate rind and walnut hull. It brings together plant-residue sourcing, controlled extraction, cotton preparation, fitkari treatment, tonal variation, fastness evaluation, water accounting and fashion-design application. The approach recognises that natural colourants must be judged through measurable textile and process outcomes rather than their biological origin alone.

The proposed method requires pilot trials to establish extraction conditions, tonal levels, mordant sequence and practical liquor ratios. The main comparison should use documented samples, consistent processing conditions, appropriate controls and independent repeats. Water should be measured at every relevant stage, and any reuse trial should be treated as a separate investigation. Since verified performance data are not available in the supplied thesis material, no final ranking of the three dye sources or quantified water-saving claim is made.

Further work should complete the experimental series, obtain instrumental colour and fastness measurements where possible, compare fresh-water and reuse conditions, and assess the selected fabrics in relation to specific product requirements. The research can then provide a stronger evidence base for the use of naturally dyed cotton in sustainable fashion design.

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