JOURNAL OF CREATIVE WRITING
VOLUME 10 ISSUE 2
2026, pp. 1–21
ISSN 2410-6259
© SARNA ALOM
https://doi.org/10.70771/JOCW.254

EVALUATION OF TROPICAL ALMOND LEAF EXTRACT FOR SUSTAINABLE DYEING OF COTTON KNITTED FABRICS UNDER DIFFERENT CHEMICAL CONDITIONS

SARNA ALOM[1]

ABSTRACT

Natural dyes are being reconsidered as sustainable alternatives to synthetic dyes, but the dyeing behavior of tropical almond (*Terminalia catappa* L.) leaf extract on cotton knit fabric, and the need for salt and soda in exhaust dyeing, are not well documented. This experimental study compared the dyeing of 100% cotton knit fabric (160 g/m²) with an aqueous tropical almond leaf extract with and without salt and soda. The dye was extracted in water and applied by the exhaust method (60 °C, 60 min, liquor ratio 1:10). Dyed samples were tested for dry and wet rubbing, water, washing, and perspiration (acid and alkali) fastness using the ISO 105 grey scales, and color strength (K/S) was measured by spectrophotometry. The extract was characterized by pH, soluble matter, and FT-IR spectroscopy. With and without salt and soda, ratings were identical for dry rubbing (4), water (4), washing (color change 3–4), and perspiration (3–4, acid and alkali). Wet rubbing was 3–4 with and 3 without salt and soda. The highest K/S was 3.75 with and 3.5 without salt and soda, at 370 nm. FT-IR showed hydroxyl, carbonyl, and aromatic bands consistent with polyphenolic compounds. Tropical almond leaf dye gave moderate-to-good fastness on cotton. Omitting salt and soda lowered only wet rubbing fastness and color strength slightly, suggesting a possible cost saving that should be confirmed with replicated trials and a fixing agent to improve wet fastness.

KEYWORDS

Natural Dye, Tropical Almond, Terminalia catappa Linn, Cotton Fabric, Color Fastness, Eco-friendly Dyeing, Sustainable Textile

INTRODUCTION

Textile dyeing is one of the oldest human technologies. Colorants from plants, insects, and minerals were used for thousands of years before the discovery of the first synthetic dye, mauveine, in 1856 (Berkli et al., 2024; Johnston, 2008; Saxena & Raja, 2014; Wilson, 2004). Synthetic dyes then came to dominate the industry because they offer a wider range of shades and more reproducible results.

Today the dyeing industry is criticized for water pollution and chemical waste, which has renewed interest in more sustainable practices, including the revival of natural dyes (Saxena & Raja, 2014). Natural dyes, however, bring their own difficulties: extraction can be slow, fastness on cellulosic fibers is often limited, and shades can vary between batches.

[1] Narsingdi Textile Engineering College (affiliated with Bangladesh University of Textiles), Narsingdi, Bangladesh. Email: sarnaalom@gmail.com. ORCID: 0009-0007-2458-7116

Tropical almond (*Terminalia catappa* L.) is a widely distributed tropical tree whose fallen leaves are an abundant, low-cost waste resource (Purnama et al., 2019; Vadwala et al., 2017). Leaf extracts have been used to dye silk and nylon (Vadwala & Kola, 2017; Vadwala et al., 2017), and the fruit has been applied to cotton (Ibrahim et al., 2021). To our knowledge, however, the leaf extract has not been applied to cotton knit fabric, a major apparel substrate, and the role of the salt and soda normally added when dyeing cotton is unclear. The present study addresses this problem.

Research Problem

Two practical problems motivate this study. First, aqueous extraction of tropical almond leaves is time-consuming, which limits its use in routine dyeing. Second, in preliminary work the dyed fabric showed a different shade with and without salt and soda, so it was unclear whether these additives are needed and whether they change color strength and fastness enough to justify their cost and effluent load. The research problem is therefore: how does the addition of salt and soda affect the color strength and color fastness of cotton knit fabric dyed with tropical almond leaf extract?

Research Aim

To extract natural dye from tropical almond (*Terminalia catappa* L.) leaves, apply it to 100% cotton knit fabric with and without salt and soda, and compare the resulting color strength (K/S) and color fastness.

Research Objectives

The specific objectives of this study were:

a) To extract natural dye from tropical almond (*Terminalia catappa* L.) leaves.
b) To apply the extracted dye on cotton fabrics.
c) To evaluate the color fastness properties.
d) To evaluate the color strength.
e) To compare dyeing with and without salt and soda in terms of color strength and fastness, in order to judge whether these chemicals (and their cost) can be reduced.
f) To characterize the leaf extract (pH, soluble matter, FT-IR) to help explain its behavior on cotton.

Research Questions and Hypotheses

RQ1. What color fastness grades (dry and wet rubbing, water, washing, perspiration) does tropical almond leaf dye achieve on 100% cotton knit fabric?

RQ2. How does adding salt and soda during exhaust dyeing affect color strength (K/S) and color fastness compared with dyeing without them?

RQ3. Which functional groups in the leaf extract (FT-IR) help explain the dye's behavior on cotton?

RQ4. Can salt and soda be omitted to reduce dyeing cost without an unacceptable loss of quality?

H_0: There is no difference in color strength or color fastness between cotton knit fabric dyed with and without salt and soda.

H_1: Cotton knit fabric dyed with salt and soda has higher color strength and/or better color fastness than fabric dyed without them.

LITERATURE REVIEW

Research on tropical almond as a textile dye falls into three groups: characterization and extraction of the colorant, application to different fibers, and the effect of auxiliaries on

fastness. The key studies are summarized below.

Purnama et al. (2019) extracted dye from tropical almond leaves and characterized the extract, establishing its basic extraction behavior.

Kumarmath et al. (2022) reviewed methods for extracting dye from tropical almond hulls and their suitability for textile use.

Jothi (2008) optimized the aqueous extraction of dye from African marigold flowers, providing process parameters that can inform extraction from other plant sources.

Vadwala et al. (2017) extracted dye from waste tropical almond leaves and applied it to silk pretreated with eco-friendly and non-eco-friendly mordants, reporting color fastness, color scale, and color strength.

Muhammadu et al. (2017) characterized the colorant in almond leaf extracts. They reported chromophores and aromatic groups, found methanol to be the most effective solvent, and identified quinone as the main dye compound, suggesting anthraquinone, naphthoquinone, and indigoid types.

Ibrahim et al. (2021) examined the effect of salt, ash, and potash on the fastness of color extracted from Indian almond fruit on cotton fabric.

Vadwala and Kola (2017) dyed nylon with tropical almond leaf dye and reported its fastness properties.

Kasembunyakorn et al. (2012) studied the effect of a tannin mordant on the color and wash durability of silk dyed with tropical almond leaves.

Taken together, these studies show that tropical almond leaves yield a usable colorant containing polyphenolic or quinone-type compounds, and that fastness has been examined mainly on silk and nylon. Only Ibrahim et al. (2021) examined salt-type auxiliaries on cotton, and they used the fruit rather than the leaf.

Research Gap

1. **Substrate and plant part:** Tropical almond dyeing has mostly been reported on silk and nylon (Vadwala & Kola, 2017; Vadwala et al., 2017), or on cotton with the fruit (Ibrahim et al., 2021). To our knowledge, the leaf extract on 100% cotton knit fabric has not been reported.
2. **Salt and soda in exhaust dyeing:** Salt and soda influence dye uptake and fixation, but their effect on leaf-extract dyeing of cotton, including color strength and a full fastness profile, has not been quantified, and the cost implication has not been assessed.
3. **Color consistency:** Little is known about how reproducible the shade is when cotton is dyed with tropical almond leaf extract.

This study addresses the first two gaps by comparing the color strength and fastness of cotton knit fabric dyed with tropical almond leaf extract with and without salt and soda.

Research Design

This study used a quantitative, experimental, two-treatment comparative design. The independent variable was the dyeing condition (Treatment A: dye liquor with salt and soda; Treatment B: dye liquor without salt and soda). The dependent variables were the color fastness grades (dry and wet rubbing, water, washing, perspiration in acid and alkali), color strength (K/S), and the FT-IR profile of the extract. Fabric (100% cotton knit, 160 g/m²), dye liquor concentration, liquor ratio (1:10), temperature (60 °C), total time (60 min), and leveling agent were kept constant. [Authors to state the number of replicate dyeings and test specimens per treatment.] The workflow is summarized below.

Diagram showing the extraction of color and dyeing procedure:

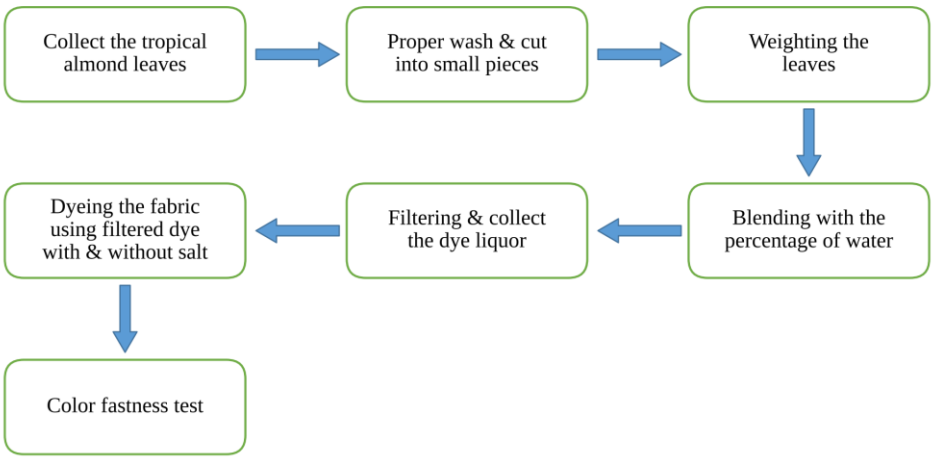


Figure 1: Extraction of color and dyeing procedure

METHODOLOGY

Dyeing 100% cotton knit fabric with natural dyes extracted from tropical almonds (*Terminalia catappa* Linn) leaves. Here's a detailed outline of the materials and methods that we used in this process:

Materials

Plant Materials:

Tropical Almond Leaves: Fresh leaves of Terminalia catappa.

Terminalia catappa L. (tropical or Indian almond) is a large tropical tree native to the Indian Ocean region (Purnama et al., 2019). Fresh, mature leaves were used. [Authors to add the collection site and date, plant identification, and whether the leaves were used fresh or dried.]

Fabrics:

100% Cotton Fabric: Knit Fabric (bleached).

Knitted cotton fabric is a type of fabric made by interlocking loops of cotton yarn, creating a stretchy, breathable, and soft material. Knitted fabric is a textile that results from Knitting, the process of inter-looping yarn Or inter-meshing of loops. Its properties are Distinct from woven fabric in that it is more Flexible and can be more readily constructed Into smaller pieces, making it ideal for socks and hard.

Detailed Information on 100% cotton knitted fabric Physical properties

- **Fiber Content:** 100% cotton
- **Yarn Type:** Combed cotton yarn 40Ne.
- **Fabric Weight:** 160 grams per square meter.
- **Abrasion Resistance:** Moderate abrasion resistance, suitable for everyday wear and tear.
- **Moisture Absorption:** High moisture absorbency due to the hydrophilic nature of cotton fiber.
- **Thermal Conductivity:** Good thermal conductivity, making it comfortable to wear in warm climates as it allows heat to escape.

Salt:

- Salt reduces the negative charge from the dye during dyeing.
- It acts as glue, holding the dye molecules in the cloth.
- It acts as an exhausting agent. (Wolela, 2021)

Soda:

- Improving dye absorption.
- Enhancing dye fixation.
- Improving fabric properties.

Equipment:

- **Blender Machine:** To blend almond leaves.
- **Stainless Steel Non-Reactive Pots:** For boiling and dyeing.
- **Stirring Rods:** These are used to stir the dye bath.
- **Measuring Cups and Spoons:** These are used to measure ingredients accurately.
- **Gloves:** For protecting hands.
- **Clothespins and Lines:** These are for hanging fabrics to dry

Dye Extraction and Dyeing Procedure

Preparation of the Dye Extract

- **Collecting and Preparing Plant Material:** Gather fresh leaves from the tropical almond tree.

Extraction Process:

Several extraction methodologies exist for natural dyes that are cost-effective and eco-friendly, such as simple aqueous methods, complicated solvent systems, supercritical fluid extraction, and ultrasonic extraction.(Purnama et al., 2019) This study used the simple aqueous method to extract the Terminalia catappa leaves. The steps in manufacturing natural dye from tropical almond leaves are as follows

1. Wash the tropical almond leaves thoroughly.
2. Cut the tropical almond leaves into small pieces, using only mature fresh leaves.
3. Weigh 200 grams of leaves and add 0.465 liter of water.
4. Soak the cut tropical almond leaves.
5. Blend the leaves with a blender machine.
6. Filtering the extracted solution.

Dyeing procedure Method: Exhaust

Recipe: Cotton fabric dyeing recipe with salt soda.

Table 1: Cotton dyeing recipe with salt and soda

Dye liquor(30% Concentration)	100 ml
Fabric	10 gm
Salt	8 gm
Soda	2 gm
Leveling agent	1 gm
Temp.	60°C
Time	60 min
M: L	1:10

Sample: 100% Cotton Knit Fabric

Fabric Weight: 10 gm

Fabric GSM: 160

Procedure:

1. Take the stainless steel non-reactive pot and mix all ingredients dye liquor, salt, leveling agent according to the recipe.
2. Put the pot in the dyeing machine chamber.
3. Set the time for 30 min.
4. After 30 min add soda. And run the machine for 30 min also.
5. Then dyeing is completed, and then cooling and rinsing are done.

Hot wash and Rinsing:

- Remove the fabrics from the dye bath and rinse in cold water until the water runs clear.
- Wash the dyed fabrics in a mild detergent to remove any excess dye.
- Rinse thoroughly and air dry the fabrics away from direct sunlight to prevent fading.



Figure 2: Dyed fabric with salt and soda

Recipe: Cotton fabric dyeing recipe without salt soda.

Table 2: Cotton dyeing recipe without salt and soda

Dye liquor(30% Concentration)	100 ml
Fabric	10 gm
Leveling agent	1 gm
Temp.	60°C
Time	60 min
M:L	1:10

Sample: 100% Cotton Knit Fabric

Fabric Weight: 10 gm

Fabric GSM: 160

Procedure:

1. Take the stainless steel non-reactive pot and mix all ingredients dye liqure, Leveling agent according to the recipe.
2. Put the pot in the dyeing machine chamber.
3. Set the time for 60 min.
4. After 60 min dyeing is completed, and then cooling and rinsing are done.

Hot wash and Rinsing:

- Remove the fabrics from the dye bath and rinse in cold water until the water runs clear.

- Wash the dyed fabrics in a mild detergent to remove any excess dye.
- Rinse thoroughly and air dry the fabrics away from direct sunlight to prevent fading.



Figure 3: Dyed fabric without salt and soda

Instrumentation

Fastness was tested using the ISO 105 series (rubbing, ISO 105-X12; washing, ISO 105-C06; water, ISO 105-E01; perspiration, ISO 105-E04) and graded with the ISO grey scales for change in color and for staining (ISO 105-A02 and ISO 105-A03; International Organization for Standardization [ISO], 1993a, 1993b, 2010, 2013a, 2013b, 2016). [Authors to confirm the editions followed and any deviations.] The instruments were a laboratory dyeing machine, a blender for extraction, a crock meter (rubbing), a perspirometer (water, acid, and alkali tests), a washing machine or launder-o-meter, a pH meter, a spectrophotometer for K/S, and an FT-IR spectrometer (KBr pellet, 4000–400 cm^{-1}). [Authors to add the make and model of each instrument, and the illuminant and observer used for K/S.] Each test is described in the following subsections.

Dry Rubbing Test

Dry Rubbing Test for Dyed Fabrics

The dry rubbing test is a standard method which is applied for evaluating the colorfastness of dyed fabrics, specifically it indicates how well the dye adheres to the fabric under dry conditions. This test simulates the friction the fabric might encounter during wear or use, which can cause the dye to transfer from the fabric to another surface. (ISO, 2016; Suganuma, 2013)

Purpose

When subjected to dry friction, the dry rubbing test measures the dyed fabric's resistance to color transfer. This is important for determining the fabric's suitability for various applications, especially in apparel and upholstery.

Materials

Test Fabric: Dyed 100% cotton knit fabric. **Rubbing Cloth:** A piece of undyed white cotton cloth, typically standardized for testing purposes.

Rubbing Test Apparatus: Crock meter.

Rating Scale: Grey scale for staining (ISO 105-A03), to rate the degree of color transfer to the white rubbing cloth.

Procedure

Sample Preparation:

- Cut a sample of the dyed fabric, typically about 5 cm x 15 cm.
- Cut a piece of undyed white cotton cloth, about 5 cm x 5 cm.

Mounting the Fabric:

- Set the dyed fabric sample on the base of the rubbing test apparatus.
- Attach the white cotton cloth to the rubbing finger of the apparatus.

Rubbing Test:

- Set the apparatus to apply a standard force (usually around 9 Newtons for the Crock meter).
- Move the rubbing finger forward and backward over the fabric sample in a straight line for a specified number of cycles (usually ten forward and backward movements).

Wet Rubbing Test

Wet Rubbing Test for Dyed Fabrics

The wet rubbing test, also known as the wet crocking test, which evaluates the colorfastness of dyed fabrics when subjected to friction under moist/wet conditions. This test is crucial for determining the durability of the dye on the fabric, especially in applications where the fabric might come into contact with moisture. (ISO, 2016; Suganuma, 2015)

Purpose

The purpose of the wet rubbing test is to measure the resistance of the dyed fabric to color transfer when it is damp and subjected to wet condition. This helps determine the fabric's suitability for various applications, including clothing, upholstery, and other textiles that might get wet during use.

Materials

Test Fabric: Dyed 100% cotton knit fabric. **Rubbing Cloth:** A piece of undyed white cotton cloth, typically standardized for testing purposes.

Rubbing Test Apparatus: Crock meter rubbing test machine.

Water: Clean, distilled water for wetting the rubbing cloth.

Rating Scale: Gray scale for staining (to evaluate the degree of color transfer).

Procedure

Sample Preparation:

- Cut a sample of the dyed fabric, typically about 5 cm x 15 cm.
- Cut a piece of undyed white cotton cloth, about 5 cm x 5 cm.

Wetting the Rubbing Cloth: Immerse the white cotton cloth in distilled water and squeeze out excess water to ensure it is wet but not dripping.

Mounting the Fabric:

- Set the dyed fabric sample on the base of the rubbing test apparatus.
- Attach the wet white cotton cloth to the rubbing finger of the apparatus.

Rubbing Test:

- Set the apparatus to apply a standard force (usually around 9 Newtons for the Crock meter).
- Move the rubbing finger forward and backward over the fabric sample in a straight line for a specified number of cycles (usually ten forward and backward movements).

Fastness to Water Test

Fastness to Water Test for Dyed Fabrics

The fastness to water test evaluates the resistance of dyed fabrics to color bleeding or fading when come into contact with water. This test is crucial for determining the suitability of dyed fabrics for applications where they may come into contact with water, such as in clothing, home textiles, and outdoor fabrics. (ISO, 2013a; Islam et al., 2016)

Purpose

The purpose of the fastness to water test is to measure the stability of the dye on the fabric when come into contact with water. This test helps to determine if the fabric will retain its color or stain other items when wet.

Materials

Test Fabric: Dyed 100% cotton knit fabric.

Multi-fiber Adjacent Fabric: A standard multi-fiber strip containing various fiber types (e.g., cotton, wool, nylon, polyester, acrylic, acetate).

Distilled Water: To ensure no impurities affect the test results.

Perspirometer: A machine that applies a consistent pressure to fabric samples.

Glass or Plastic Containers: For immersing the fabric samples in water.

Gray Scale for Color Change: To evaluate the degree of color change in the test fabric.

Gray Scale for Staining: To evaluate the degree of staining on the adjacent fabric.

Procedure

Sample Preparation:

- Cut a sample of the dyed fabric, typically about 10 cm x 4 cm.
- Cut a piece of multi fiber adjacent fabric of the same size

Assembling the Test Sandwich: Place the multi fiber strip on top of the dyed fabric sample. Sew the edges to keep them together during the test.

Immersing in Water: Immerse the assembled fabric sample in distilled water at room temperature (around 20-30°C) for 30 minutes. Ensure the samples are fully submerged.

Removing Excess Water: After soaking, remove the fabric samples from the water and gently squeeze out excess water without twisting or wringing the fabric.

Drying Under Pressure: Place the wet fabric samples between two glass or plastic plates and apply a pressure with the help of perspirometer. Keep them under pressure for 4 hours at room temperature.

Drying the Samples: After the pressure period, separate the fabrics and allow them to air dry completely at room temperature.

Fastness to Wash Test

Fastness to Wash Test for Dyed Fabrics

The fastness to wash test evaluates the resistance of dyed fabrics to color bleeding, fading, or alteration during laundering. This test is essential for determining the durability and stability of the dye on fabrics intended for washable garments and home textiles. (ISO, 2010; Kartini et al., 2021)

Purpose

The purpose of the fastness-to-wash test is to measures the stability of the dye on the fabric when the fabric is washed. This test helps to determine whether the fabric will retain its color or stain other items during laundering.

Materials

Test Fabric: Dyed 100% cotton knit fabric. **Multitier Adjacent Fabric:** A standard multi-fiber strip containing various fiber types (e.g., cotton, wool, nylon, polyester, acrylic, acetate).

Detergent: ECEB Phosphate detergent for testing purposes.

Laundering Machine: A standard washing machine or launder-o-meter.

Gray Scale for Color Change: To evaluate the degree of color change in the test fabric.

Gray Scale for Staining: To evaluate the degree of staining on the adjacent fabric.

Procedure

Sample Preparation:

- Cut a sample of the dyed fabric, typically about 10 cm x 4 cm.
- Cut a piece of multi-fiber adjacent fabric of the same size.

Assembling the Test Sandwich:

Place the multi-fiber strip on top of the dyed fabric sample. Sew or clip the edges to keep them together during the test.

Washing Conditions:

- **Solution Preparation:** Dissolve 5 grams of standard non-phosphate detergent in 1 liter of water.
- **Temperature:** Set the washing temperature to 40°C (as specified by the testing standard).
- **Duration:** Wash the samples for 30 minutes in the prepared detergent solution.

Laundering Process:

Place the sample fabric in the washing machine or laundry meter. Add the detergent solution and set the machine running for 30 min at 40°C.

Rinsing and Drying:

After washing, rinse the sample fabric thoroughly in cool water to remove all detergent residues. Squeeze out excess water carefully and allow the samples to air dry at room temperature.

Fastness to Acid Test

Fastness to Acid Test for Dyed Fabrics

The fastness to acid test evaluates the resistance of dyed fabrics to color change when exposed to acidic conditions. This test is essential for determining the durability and stability of the dye on fabrics that might come into contact with acidic substances, such as during perspiration or exposure to acidic environments. (ISO, 2013b; Islam et al., 2016)

Purpose

The purpose of the fastness to acid test is to assess the stability of the dye on the fabric when subjected to acidic conditions. This test helps to determine if the fabric will retain its color or stain other items when come into contact with acids.

Materials

Test Fabric: Dyed 100% cotton knit fabric. **Multi-fiber Adjacent Fabric:** A standard multi-fiber strip containing various fiber types (e.g., cotton, wool, nylon, polyester, acrylic, acetate).

Recipe:

Table 3: Recipe for fastness to acid test

L-Histidine mono hydrochloride monohydrate	0.5 g/L
Sodium Chloride	5 g/L
Sodium Dihydrogen phosphate	2.2 g/L

pH Meter: To ensure the correct acidity of the solution.

Perspirometer: A machine that applies consistent pressure to fabric samples. If not available, weights can be used.

Glass or Plastic Containers: To immerse the fabric samples in the acid solution.

Gray Scale for Color Change: To evaluate the degree of color change in the test fabric.

Gray Scale for Staining: To evaluate the degree of staining on the adjacent fabric.

Procedure

Sample Preparation:

- Cut a sample of the dyed fabric, typically about 10 cm x 4 cm.
- Cut a piece of multi-fiber adjacent fabric of the same size.

Assembling the Test Sandwich: Place the multi-fiber strip on top of the dyed fabric sample. Sew the edges to keep them together during the test.

Preparing the Acid Solution: Prepare a 0.1% hydrochloric acid or a 0.5% acetic acid solution by diluting the concentrated acid with distilled water. Verify the pH of the solution, aiming for a pH between 4 and 5.

Immersing the Samples: Immerse the assembled fabric sample in the acid solution at room temperature (around 20-30°C) for 30 minutes. Ensure the samples are fully submerged.

Removing Excess Solution: After soaking, remove the fabric samples from the acid solution and carefully squeeze out excess liquid without twisting or wringing the fabric.

Drying Under Pressure: Place the wet fabric samples between two glass or plastic plates and apply consistent pressure (e.g., using a Perspirometer or weights). Keep them under pressure for 4 hours at room temperature.

Drying the Samples: After the pressure period, separate the fabrics and let them air dry completely at room temperature.

Fastness to Alkali Test

Fastness to Alkali Test for Dyed Fabrics

The fastness to alkali test evaluates the resistance of dyed fabrics to color change when exposed to alkaline conditions. This test is essential for determining the durability and stability of the dye on fabrics that might come into contact with alkaline substances, such as during laundering with alkaline detergents or exposure to sweat. (ISO, 2013b; Islam et al., 2016)

Purpose

The purpose of the fastness to alkali test is to measure the stability of the dye on the fabric when subjected to alkaline conditions. This test helps to determine if the fabric will retain its color or stain other items when exposed to alkaline environments.

Materials

Test Fabric: Dyed 100% cotton knit fabric.

Multi-fiber Adjacent Fabric: A standard multi-fiber strip containing various fiber types (e.g., cotton, wool, nylon, polyester, acrylic, acetate).

Recipe:

Table 4: Recipe for fastness to alkali test

L-Histidine mono hydrochloride monohydrate	0.5 g/L
Sodium Chloride	5 g/L
Disodium hydrogen phosphate	2.5 g/L

pH Meter: To ensure the correct alkalinity of the solution.

Perspirometer: A machine that applies consistent pressure to fabric samples. If not available, weights can be used.

Glass or Plastic Containers: To immerse the fabric samples in the alkali solution. **Gray Scale for Color Change:** To evaluate the degree of color change in the test fabric. **Gray Scale for Staining:** To evaluate the degree of staining on the adjacent fabric.

Procedure

Sample Preparation:

- Cut a sample of the dyed fabric, typically about 10 cm x 4 cm.
- Cut a piece of multi-fiber adjacent fabric of the same size.

Assembling the Test Sandwich: Place the multi-fiber strip on top of the dyed fabric sample. Sew the edges to keep them together during the test.

Preparing the Alkali Solution: Prepare a 0.5% sodium carbonate (Na_2CO_3) solution or a 0.1% sodium hydroxide (NaOH) solution by dissolving the respective chemical in distilled water.

Verify the pH of the solution, aiming for a pH between 9 and 10 for sodium carbonate or pH 11 for sodium hydroxide.

Immersing the Samples: Immerse the assembled fabric sample in the alkali solution at room temperature (around 20-30°C) for 30 minutes. Ensure the samples are fully submerged.

Removing Excess Solution: After soaking, remove the fabric samples from the alkali solution and gently squeeze out excess liquid without twisting or wringing the fabric.

Drying Under Pressure: Place the wet fabric samples between two glass or plastic plates and apply consistent pressure (e.g., using a perspirometer or weights). keep them under pressure for 4 hours at room temperature.

Drying the Samples: After the pressure period, separate the fabrics and let them air dry completely at room temperature.

Data Collection

Data came from three sources. (1) Fastness grades: after each test, the color change of the dyed specimen and the staining of the adjacent multifiber or white cloth were rated on the 1–5 grey scales (half grades allowed). [Authors to state the number of assessors and the viewing conditions.] (2) Color strength: reflectance of the dyed fabric was measured with a spectrophotometer and K/S was calculated with the Kubelka–Munk equation, $K/S = (1 - R)^2 / 2R$, over the measured wavelength range; the highest K/S and its wavelength were recorded. (3) Extract characterization: pH, soluble matter (%), and FT-IR spectra of the solid extract (KBr pellet, 4000–400 cm^{-1}). The original fastness test reports are reproduced in Figures 10 and 11.

Data Analysis

Grey-scale grades and K/S values for the two treatments were tabulated and compared descriptively using bar charts (Figures 4–9 and 12–14), and the FT-IR bands were assigned to functional groups to interpret the dye's behavior. [If replicates were measured, report means ± SD and apply a suitable test, for example an independent-samples *t* test for K/S and a Mann–Whitney *U* test for ordinal grey-scale grades; also report ΔE*ab between treatments and between replicate batches to support any claim about color consistency.]

RESULTS: COLOR FASTNESS OF COTTON DYED WITH TROPICAL ALMOND LEAF EXTRACT

When evaluating the color fastness of cotton fabric that was dyed with natural dye from the tropical almond (*Terminalia Catappa Linn*) leaves, various tests are guided to measure the stability and durability of the dye. These tests include fastness to rubbing (both dry and wet), washing, water, acid, and alkali. Below are typical results and interpretations for these tests.

Dry Rubbing Fastness

Objective: To measure the resistance of the dyed fabrics to color transfer under dry conditions.

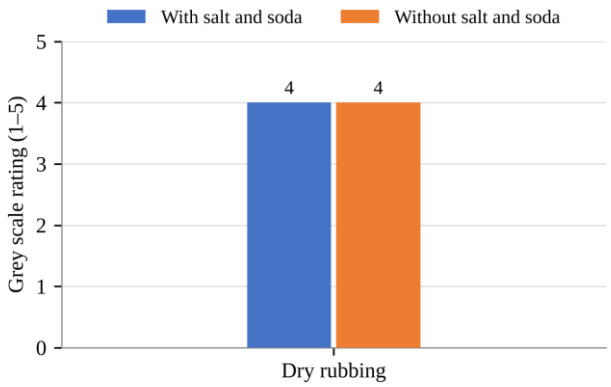


Figure 4: Dry rubbing test results

Rating: 4 (Good) for both using salt soda and without salt soda.

Interpretation: The dye shows good resistance to color transfer for both treatments when rubbed in dry conditions, indicating good adhesion to the cotton fibers.

Wet Rubbing Fastness

Objective: To measure the resistance of the dyed fabrics to color transfer under wet conditions.

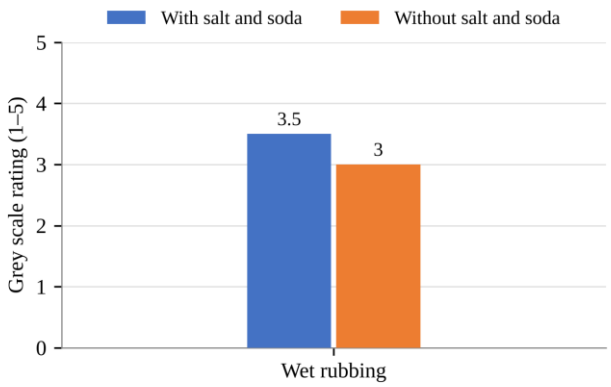


Figure 5: Wet rubbing test results

Rating: 3-4 (Average to good) for salt soda. 3 (Average) for without salt soda.

Interpretation: The dye shows average resistance to color transfer but comparatively good for using salt soda when rubbed in wet conditions, indicating good adhesion to the cotton fibers.

Washing Fastness

Objective: To measure the stability of the dye on the fabrics when subjected to standard washing conditions.

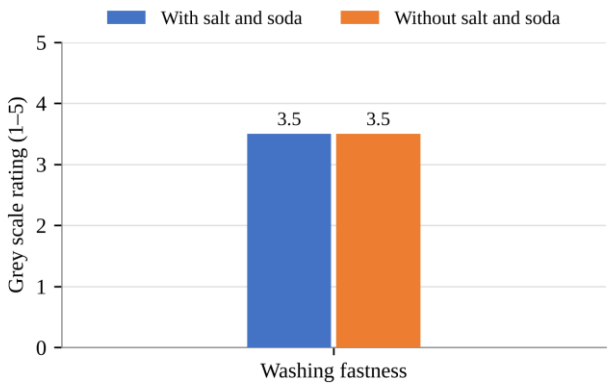


Figure 6: Washing fastness results

Color Change Rating: 3-4 (Average to Good) for both using salt soda and without salt soda. **Color Staining Rating:** 4-5 (Good to Excellent) for both using salt soda and without salt soda. **Interpretation:** The dye shows good stability during washing at the rating 3-4 (Average to Good) for color change and 4-5 (Good to Excellent) for color staining. Because both treatments gave the same rating, salt and soda could potentially be omitted for this property.

Water Fastness

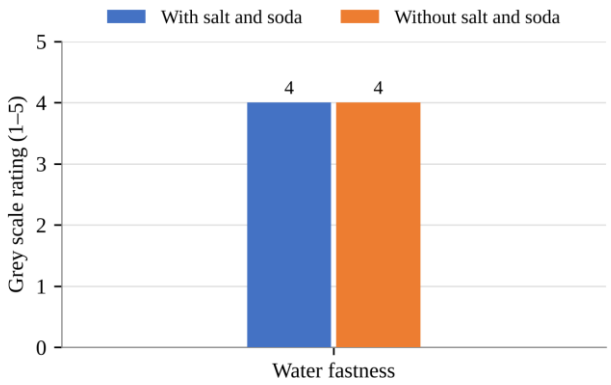


Figure 7: Water fastness results

Color Change Rating: 4 (Good) for both using salt soda and without salt soda.

Color Staining Rating: 4 (Good) for both using salt soda and without salt soda.

Interpretation: The dye exhibits good stability in water, with minimum color for both using

salt soda and without salt soda. Because both treatments gave the same rating, salt and soda could potentially be omitted for this property.

Perspiration Fastness (Acid)

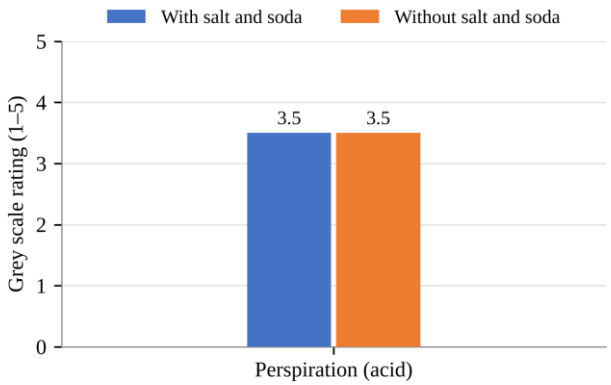


Figure 8: Fastness to perspiration (acid) results

Color Change Rating: 3-4 (Average to Good) for both using salt soda and without salt soda.
Color Staining Rating: 4-5 (Good to excellent) for both using salt soda and without salt soda.
Interpretation: The dye exhibits good stability and medium resistance to acidic conditions, with minimum color. Because both treatments gave the same rating, salt and soda could potentially be omitted for this property.

Perspiration Fastness (Alkali)

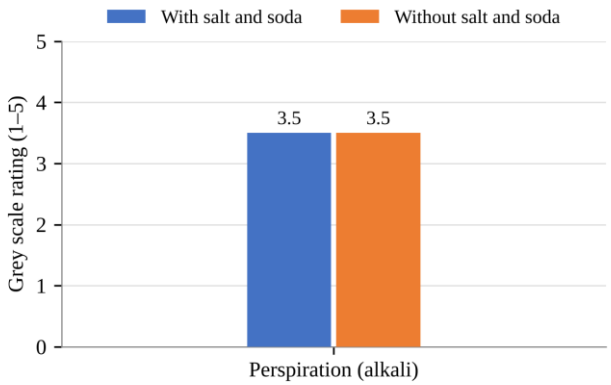


Figure 9: Fastness to perspiration (alkali) results

Color Change Rating: 3-4 (Average to Good) for both using salt soda and without salt soda.
Color Staining Rating: 3-4 (Average to Good) for both using salt soda and without salt soda.
Interpretation: The dye exhibits good stability and medium resistance to alkaline conditions, with minimum color. Because both treatments gave the same rating, salt and soda could potentially be omitted for this property.

Fastness Test Reports

Fastness report (With salt soda):

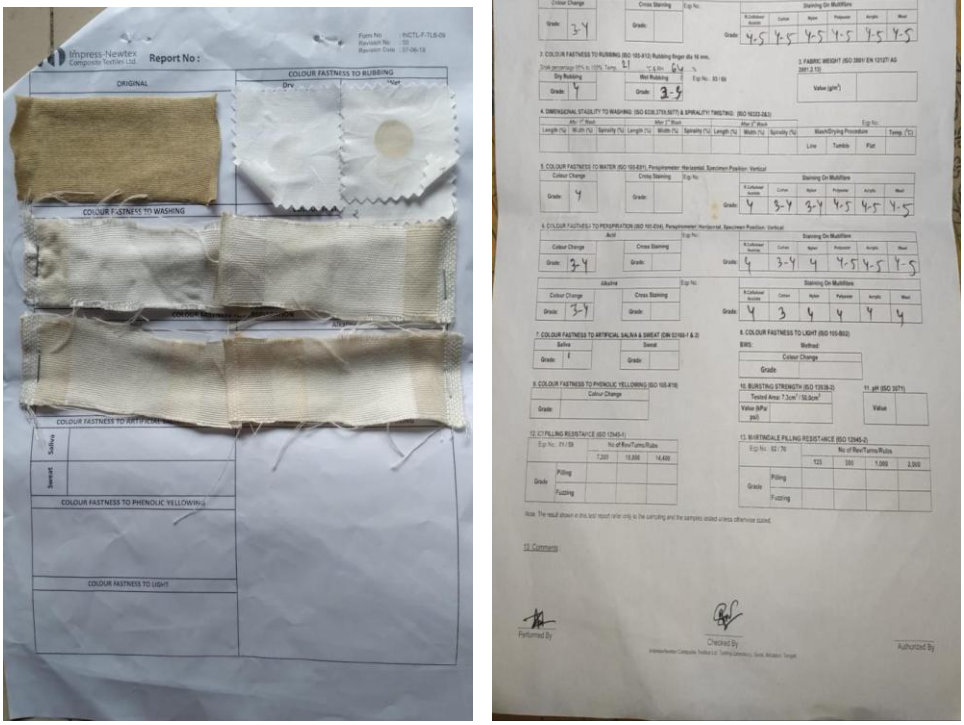


Figure 10: Fastness report (with salt and soda)

Fastness report (Without salt soda):

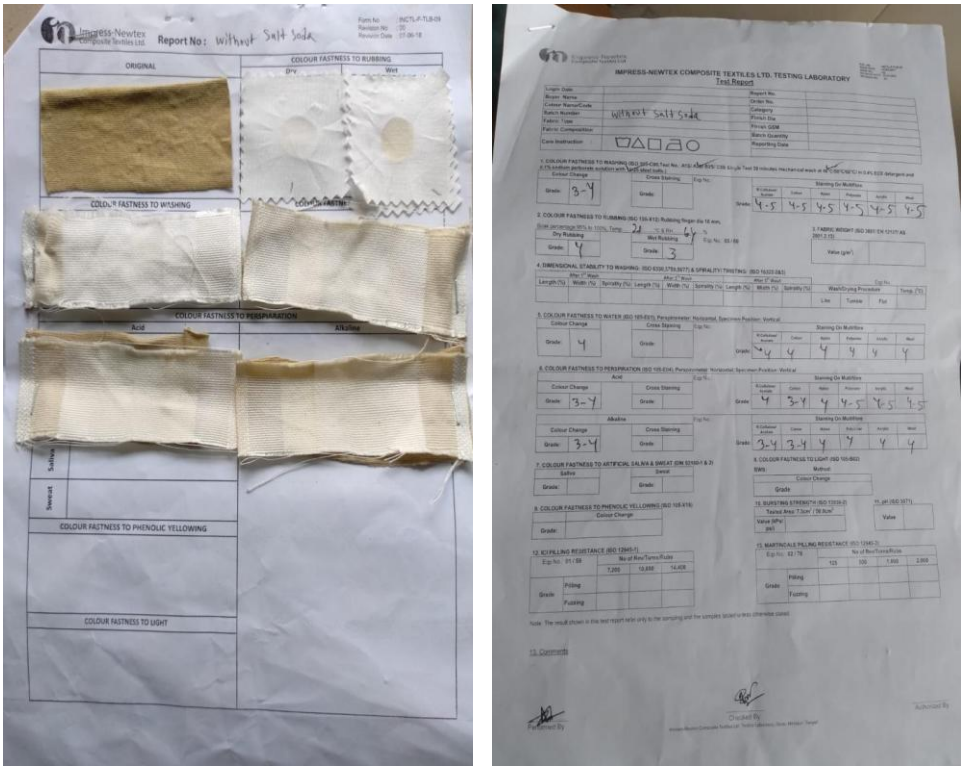


Figure 11: Fastness report (without salt and soda)

Graph Chart on Results

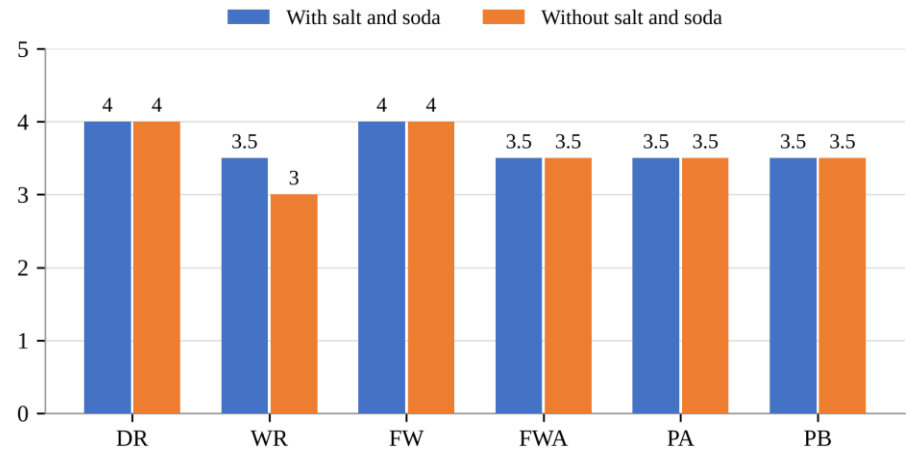


Figure 12: Fastness results. DR = dry rubbing; WR = wet rubbing; FW = fastness to water; FWA = fastness to washing; PA = perspiration (acid); PB = perspiration (alkali)

Color Strength (K/S) Results

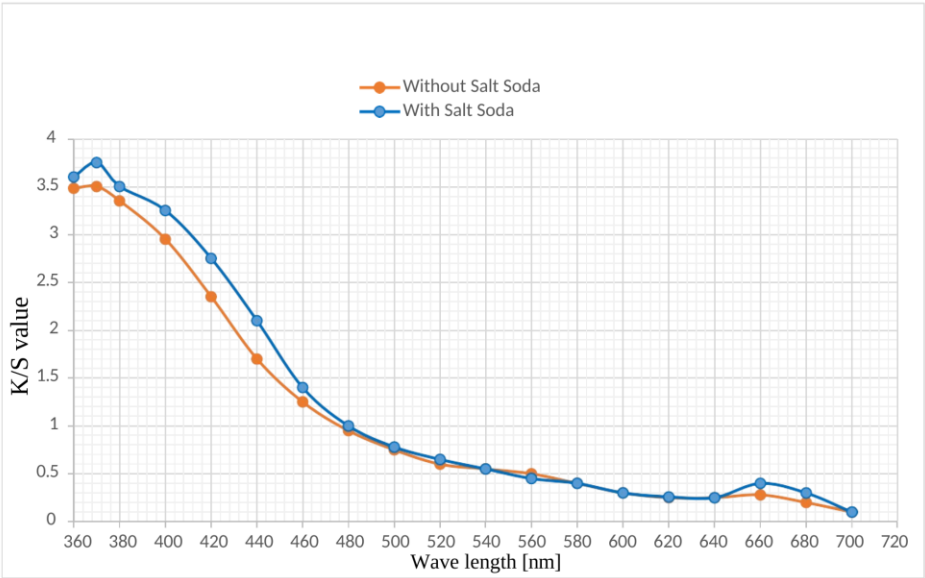


Figure 13: Color strength (K/S) of dyed cotton across wavelengths

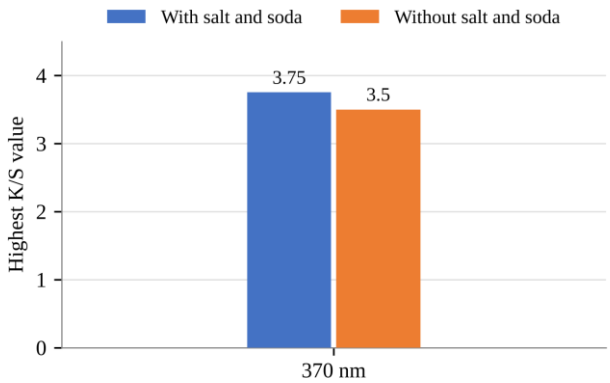


Figure 14: Highest color strength (K/S) value at 370 nm

Color strength k/s value is measured by a spectrophotometer. This value shows the ratio of the absorption coefficient (K) and the scattering coefficient (S). Here, the result exhibits the highest K/S value 3.75 for dyed fabric with salt soda & 3.5 for dyed fabric without salt soda at 370 nm**.**

Characterization of the Leaf Extract

The color was taken out using water only, without using any chemicals. The pH of the color solution was tested and found to be acidic. The color looked dark brownish yellow. To make sure the same shade can be made again, the amount of soluble matter (the part that mixes in water) was measured. It was found to be 2%.

The functional groups (special chemical parts) in the Tropical Almond leaf extract were studied using FT-IR (Fourier Transform Infrared) spectroscopy. This test was done in the range of 4000 to 400 cm^{-1}. To do this, the solid dye extract was mixed with a substance

called KBr and pressed into a thin, flat shape (called a pellet). The IR results are shown in a graph.

Comparison with Nylon and Silk (Data from Previous Studies)

We work on cotton fabric for this project and other nylon and silk fabric result data collected from "Natural dyes extracted from waste leaves of *Terminalia catappa* locally known as tropical almond and its application on silk fabrics pre-treated with eco-friendly" (Vadwala et al., 2017) and "Dyeing on nylon fabric with natural dye extracted from waste leaves of *Terminalia catappa* locally known as tropical almond tree" (Vadwala & Kola, 2017)

Table 5: Comparison table of results

Fabric Type	DR (1-5)	WR (1-5)	F Water (1-5)	F Wash (1-5)	PA (1-5)	PB (1-5)	Comments
Cotton	4	3-4	4	3-4	3-4	3-4	Over all good
Nylon	5	4		5	5	5	Over all Excellent
Silk	5	3		5	4	4-5	Over all good

Objective: Compare the resistance of the dyed fabrics to color change between cotton, nylon and silk with dry rubbing, wet rubbing, water, wash and perspiration to acid and alkali conditions.

DISCUSSION

Principal findings. Dyeing with and without salt and soda gave identical grades for dry rubbing (4), water fastness (4), washing (color change 3–4, staining 4–5), and perspiration (color change 3–4, acid and alkali). Differences appeared only in wet rubbing (3–4 with versus 3 without) and in peak color strength (K/S 3.75 versus 3.5, about 7% higher with salt and soda). Because a single additive combination was compared and no statistical test was applied, these differences should be read as small and indicative rather than as proof of no effect.

Possible explanation. The FT-IR bands at 3406 cm^{-1} (O–H), 1713 cm^{-1} (C=O), 1613–1357 cm^{-1} (aromatic C=C), and 1227–1066 cm^{-1} (C–O) indicate a hydroxylated, aromatic extract. This is consistent with the flavonoid compounds proposed for this extract (Vadwala et al., 2017), although Muhammadu et al. (2017) identified quinone-type chromophores in almond leaf extract, so the chemical identity remains unresolved. Molecules of this kind have no reactive group for covalent bonding to cellulose and probably attach through hydrogen bonding and van der Waals forces, which may explain the moderate wet fastness without a mordant. Salt is generally used to promote exhaustion of dyes on cellulosic fibers (Wolela, 2021); its small effect here may mean that the extract carries little charge to be screened, but this was not tested. The slightly better wet rubbing and K/S with salt and soda are consistent with some improvement in uptake.

Comparison with other fabrics. Cotton graded lower than nylon and silk for dry rubbing and washing and similar to silk for wet rubbing (Table 5). However, the nylon and silk values come from other studies that used different dyeing conditions and, for silk, mordants (Vadwala & Kola, 2017; Vadwala et al., 2017), so the comparison is only indicative. The results should also be compared directly with those of Ibrahim et al. (2021), who tested salt, ash, and potash on cotton dyed with almond fruit extract.

Practical implications. Because fastness was the same in five of six tests, omitting salt and soda could reduce chemical use, effluent salinity, and cost. The saving was not quantified, and the lower wet rubbing grade and K/S without additives must be weighed against it. A post-treatment with a fixing agent may improve wet fastness.

Limitations. (a) Salt and soda were removed together, so their separate effects cannot be

distinguished. (b) The number of replicates is not reported and no statistical test was applied. (c) Color consistency, named in the original title and problem statement, was not measured (no ΔE*ab or batch-to-batch data). (d) One leaf batch, one fabric, and no mordant or fixing agent were tested. (e) Grey-scale grading is subjective. (f) Extraction conditions were not fully specified, which limits reproducibility.

CONCLUSION

The overall color fastness results of cotton fabric dyed with tropical almond leaves, both with and without the use of salt soda, are quite satisfactory. In the case of dry rubbing, both methods show good fastness resistance. For wet rubbing, dyeing with salt soda gives average to good results, while dyeing without salt soda shows average performance. Washing fastness is average to good in both cases. Water fastness also shows good resistance in both cases. Acid and alkali fastness results are similarly average to good for both methods. These findings indicate that tropical almond dye provides reasonably good fastness properties in both situations, making it suitable for various textile uses.

This study contributes by showing that dyeing with and without salt and soda gave identical fastness grades in five of six tests, with only slightly lower wet rubbing fastness and color strength (K/S 3.5 versus 3.75) when they were omitted. The overall color fastness of fabric dyed with tropical almond leaves is good. Moreover, the process can be carried out without salt soda, which may help reduce the overall dyeing cost.

RECOMMENDATIONS AND FUTURE RESEARCH

To improve the color fastness results, post-dyeing treatments such as the use of fixing agents are recommended, especially to enhance performance under wet conditions. Additionally, optimizing the dyeing process by carefully controlling factors like temperature, pH level, and dyeing time can help achieve better fastness properties overall.

Future research should (1) test salt and soda separately and at several concentrations, (2) run replicated dyeings and compare K/S and ΔE*ab statistically, (3) quantify the cost and effluent savings, (4) examine mordants or fixing agents to improve wet fastness, and (5) standardize extraction time, temperature, and leaf maturity to improve batch-to-batch consistency.

REFERENCES

Berkli, Y., Zencirkıran, A., & Yılmaz, F. (2024). The history of natural dyeing and investigation of the antibacterial activity of *Hibiscus sabdariffa* L. on woolen fabrics. *Pigment & Resin Technology, 53*(6), 833–840.

Ibrahim, A. U., Keturah, A. Y., Lydia, D., Appollm, Y. I., & Ibrahim, F. J. (2021). Evaluation of salt, ash and potash on fastness properties of colour extracted from Indian almond fruit (*Terminalia catappa*) on cotton fabric. [Publication source to be completed.]

International Organization for Standardization. (1993a). *Textiles—Tests for colour fastness—Part A02: Grey scale for assessing change in colour* (ISO 105-A02:1993).

International Organization for Standardization. (1993b). *Textiles—Tests for colour fastness—Part A03: Grey scale for assessing staining* (ISO 105-A03:1993).

International Organization for Standardization. (2010). *Textiles—Tests for colour fastness—Part C06: Colour fastness to domestic and commercial laundering* (ISO 105-C06:2010).

International Organization for Standardization. (2013a). *Textiles—Tests for colour fastness—Part E01: Colour fastness to water* (ISO 105-E01:2013).

International Organization for Standardization. (2013b). *Textiles—Tests for colour fastness—Part E04: Colour fastness to perspiration* (ISO 105-E04:2013).

International Organization for Standardization. (2016). *Textiles—Tests for colour fastness—*

Part X12: Colour fastness to rubbing (ISO 105-X12:2016).

Islam, M., Hasan, K. F., Deb, H., Faisal, A. M. M., & Xu, W. (2016). Improving the fastness properties of cotton fabric through the implementation of different mordanting agents dyed with natural dye extracted from marigold. *American Journal of Polymer Science and Engineering, 4*(1), 1–17.

Johnston, W. T. (2008). The discovery of aniline and the origin of the term "aniline dye." *Biotechnic & Histochemistry, 83*(2), 83–87.

Jothi, D. (2008). Extraction of natural dyes from African marigold flower (*Tagetes erecta* L.) for textile coloration. *AUTEX Research Journal, 8*(2), 49–53.

Kartini, I., Halimah, S. N., & Rahayuningsih, E. (2021). Enhanced wash-fastness of cotton fabric dyed with a composite of chitosan–natural dyes extract of *Ceriops tagal*. *IOP Conference Series: Materials Science and Engineering*, Article 012022.

Kasembunyakorn, S., Pornsuda, M., & Arirob, W. (2012). Effect of tannin mordant on silk dyed with tropical almond leaves (*Terminalia catappa* Linn.). *Journal of ARAHE, 19*(72), 174.

Kumarmath, P., Kawatal, A., & Nimbargi, K. (2022). A review on extraction of dye from *Terminalia catappa* hull: A substitute to synthetic dyes. *Journal of Emerging Technologies and Innovative Research, 9*(2).

Muhammadu, A. B., Hassan, A., & Okezi, R. M. (2017). Characterisation of colourant extracted from almond leaves. *Nigerian Journal of Chemical Research, 22*(2), 31–44.

Purnama, H., Eriani, W., & Hidayati, N. (2019). Natural dye extraction from tropical almond (*Terminalia catappa* Linn) leaves and its characterization. *AIP Conference Proceedings, 2114*(1).

Saxena, S., & Raja, A. S. M. (2014). Natural dyes: Sources, chemistry, application and sustainability issues. In S. S. Muthu (Ed.), *Roadmap to sustainable textiles and clothing: Eco-friendly raw materials, technologies, and processing methods* (pp. 37–80). Springer.

Suganuma, K. (2013). Effect of the rubbing force on dry rubbing fastness with various white cloths. *Coloration Technology, 129*(6), 443–447.

Suganuma, K. (2015). Improvement of the standard method for assessing colour fastness to wet rubbing. *Coloration Technology, 131*(5), 403–411.

Vadwala, Y., & Kola, N. (2017). Dyeing on nylon fabric with natural dye extracted from waste leaves of *Terminalia catappa* locally known as tropical almond tree. *International Journal of Home Science, 3*(2), 175–181.

Vadwala, Y., Kola, N., & Patel, S. M. (2017). Natural dyes extracted from waste leaves of *Terminalia catappa* locally known as tropical almond and its application on silk fabrics pre-treated with ecofriendly and noneco-friendly mordants. *International Journal of Research, 5*(5).

Wilson, A. (2004). Production and dyeing in Roman [complete title, editors, and publisher to be verified]. *Purpureae Vestes, 1*, 155.

Wolela, A. D. (2021). Effect and role of salt in cellulosic fabric dyeing. *Advances in Research in Textile Engineering, 6*(1), 1061.