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Dyeing Performance of Curcumin and Tannin-Based Extracts from *Curcuma longa* and *Acacia nilotica* Pods on Nylon 6,6 Fabrics

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ABSTRACT

This study investigates the application of a bi-herbal natural dye system derived from turmeric root (*Curcuma longa*) and *Acacia nilotica* pods on Nylon 6,6 fabric as a sustainable alternative to synthetic dyes. Dye extracts were obtained via Soxhlet extraction using methanol and characterized using melting point determination, UV-Visible spectroscopy, and FT-IR analysis. The bi-herbal dye mixture exhibited a melting point range of 119–122 °C and a yield of 48%, indicating thermally stable phytochemicals. UV–Vis analysis revealed a maximum absorption at 493 nm, confirming the presence of conjugated chromophores. FT-IR spectra indicated phenolic O-H, aromatic C=C, and C=O functional groups typical of polyphenols and tannins. Dyeing performance on Nylon 6,6 using copper and zinc sulfate mordants showed good colouration, with zinc mordant producing brighter shades and superior fastness properties. Fastness results showed moderate to good wash fastness (3/4-4) and good to very good light fastness (5-6), with zinc mordant outperforming copper. The findings demonstrate that Turmeric-Acacia bi-herbal dyes offer an eco-friendly and effective alternative for dyeing synthetic fibres.

KEYWORDS: *Acacia nilotica*, Bi-herbal dye, *Curcuma longa*, Fastness properties, Natural dyes, Nylon 6,6.

INTRODUCTION

The textile industry is one of the largest consumers of synthetic dyes, contributing significantly to environmental pollution through the discharge of toxic effluents. Synthetic dyes often contain hazardous aromatic amines and heavy metals that pose risks to aquatic ecosystems and human health. As a result, there is increasing global interest in the development of sustainable and eco-friendly alternatives [1].

Natural dyes, derived from plant, animal, and mineral sources, offer a promising solution due to their biodegradability, non-toxicity, and renewable nature. However, their application is often limited by poor fastness properties and low affinity for synthetic fibres.

Turmeric, a well-known natural dye source, contains curcuminoids such as curcumin, which possess strong chromophoric properties due to extended conjugation. These compounds absorb visible light efficiently, producing bright yellow coloration. On the other hand, *Acacia nilotica* pods are rich in tannins, which are polyphenolic compounds known for their ability to bind strongly to fibres and metal ions [2]. The combination of these two plant sources forms a bi-herbal dye system, where turmeric provides colour intensity while *Acacia nilotica* enhances dye fixation and fastness. This interaction is particularly important when dyeing synthetic fibres such as Nylon 6,6.

Nylon 6,6 is a polyamide fibre characterized by repeating amide (-CONH-) groups, which allow hydrogen bonding and ionic interactions with dye molecules. Despite this, its dyeing typically requires synthetic acid dyes. The use of natural dyes on nylon remains underexplored, especially in bi-herbal systems [3]

This study therefore aims to develop a bi-herbal dye system, combining turmeric and *Acacia nilotica* to improve dye uptake, colour variation, fastness properties on Nylon 6,6 fabric and compare the effect of metal mordants (Cu^{2+} and Zn^{2+})

MATERIALS AND METHODS

Materials

Materials used include methanol, ethanol, distilled water, sodium chloride, sodium carbonate, copper sulfate, zinc sulfate, and Nylon 6,6 fabric. Plant samples of turmeric root (*Curcuma longa*) and *Acacia nilotica* pods were collected and authenticated at the Herbarium, Department. of Biological Sciences, Ahmadu Bello University, Zaria, with the issued voucher number ABU06805 for *Curcuma longa* and ABU01816 for *Acacia nilotica*.

Extraction of Dye

Powdered plant samples (50 g each of *Acacia nilotica pods and Curcuma longa* root) were subjected to Soxhlet extraction using methanol for 4 hours. Extracts were concentrated and dried to obtain crude dye.

Characterization

Determination of Melting point: The melting point of the bi-herbal dye extract was determined by using Gallenkamp melting point apparatus.

Determination of UV–Vis spectroscopy: The Agilent CARY 300 UV-visible spectrophotometer was used. The cell used for the spectroscopic analysis was washed with distilled water and dried. Distilled water was put into the cell to take the blank. This was followed by taking 5.0 mL of the solution of the bi-herbal dye (0.00005 mol/L) to reduce the concentration of the dye samples. The absorbance of dye samples was determined using spectrophotometer machine (UV-visible spectroscopy) within the visible region (i.e. 400-800 nm), in order to determine the wavelength of maximum absorption.

Determination of FT-IR spectroscopy: Agilent CARY 630 FT-IR spectrometer machine was used for the determination of IR-spectroscopy of the natural dye sample in order to ascertain the functional groups present in the bi-herbal dye mixture.

Dyeing Procedure

Preparation of Bi-herbal Dye

The bi-herbal dyestuff was prepared via the mixing together of equal amounts of the extracted dyestuff from turmeric root and acacia nilotica pods (2 g each) in order to enhance their dyeing effects.

Mordanting and Dyeing of Nylon 6,6 Fiber

Approximately 1 g of zinc sulfate and copper sulfate was weighed out separately and dissolved in 100 mL of hot water respectively and allowed to simmer for 10 min. Nylon 6,6 fabrics (of dimension 5 × 5 cm) was soaked separately in metal salt solution for 45 min at a temperature 60°C. The fabrics were removed and introduced into freshly prepared bi-herbal dye baths, the temperature of the baths gradually raised to 90°C and allowed to simmer for 1 h. After 1 h the dye baths were allowed to cool for 20 min, and the dyed fabrics were removed and spread at room temperature until dry [4,5].

Assessment of Fastness Properties

Wash Fastness

The dyed samples were subjected to I.S.O.3 wash fastness test by the following procedures: The specimens were prepared by cutting the dyed fibres into 5 cm x 2 cm dimensions. They were thereafter made into composites by stitching the test specimen made of the dyed sample placed in-between white cotton of dimensions 10 cm x 4 cm. The composite was agitated in the solution made up of the following:

Soap solution: 5 g/l

Sodium carbonate: 2 g/l

Liquor ratio 50:1

The washing was maintained at 50 °C for 45 minutes with continuous agitation. At the end of the washing test the composite specimen was removed, rinsed in cold water and the components separated and dried at room temperature. The change in colour of the dyed samples and the staining of adjacent undyed cloths was assessed using the appropriate grey scale [6].

Light Fastness Test

The light fastness test was carried out using 8-Blue Wool Standard. The dyed samples and blue wools standard were exposed facing due south and inclined at an angle to the horizontal approximately equal to the latitude of the place where the exposure is being made. Adequate ventilation of the samples during exposure was ensured. The partly covered samples were exposed to UV radiation. As exposure proceeded for 3 days, the samples under test and the blue wool standards were examined at intervals and the change in colour of the samples compared visually with the changes that occur in the standards. The light fastness of the sample is the number of the standard that shows a similar visual contrast between the exposed and unexposed part of the samples. The exposure was terminated when the blue wool standard 7 fades or when fully exposed and non-exposed test samples is equivalent to grade 3 on the grey scale [7]. Light fastness values for each material was obtained by comparing the degree of fading with that observed with Blue wool standard. Rating is given according to the Wool standard with which the dyed material fading is comparable.

RESULTS AND DISCUSSION

The physical properties of the extracted bi-herbal dye mixture is as presented in Table 1.

Table 1: Physical Properties

Sample	Melting point (^{o}C)	% Yield	Appearance
Bi-herbal dye extract	119-122	48	Dark Brown

The UV-Visible spectrum (nm) of the bi-herbal dye extract is as presented in Figure 1 and the summary of the observed wavelength of maximum absorption is as presented in Table 2.

Table 2: UV–Visible Analysis

Sample	Wavelength (nm)
Bi-herbal Dye Extract	493.0

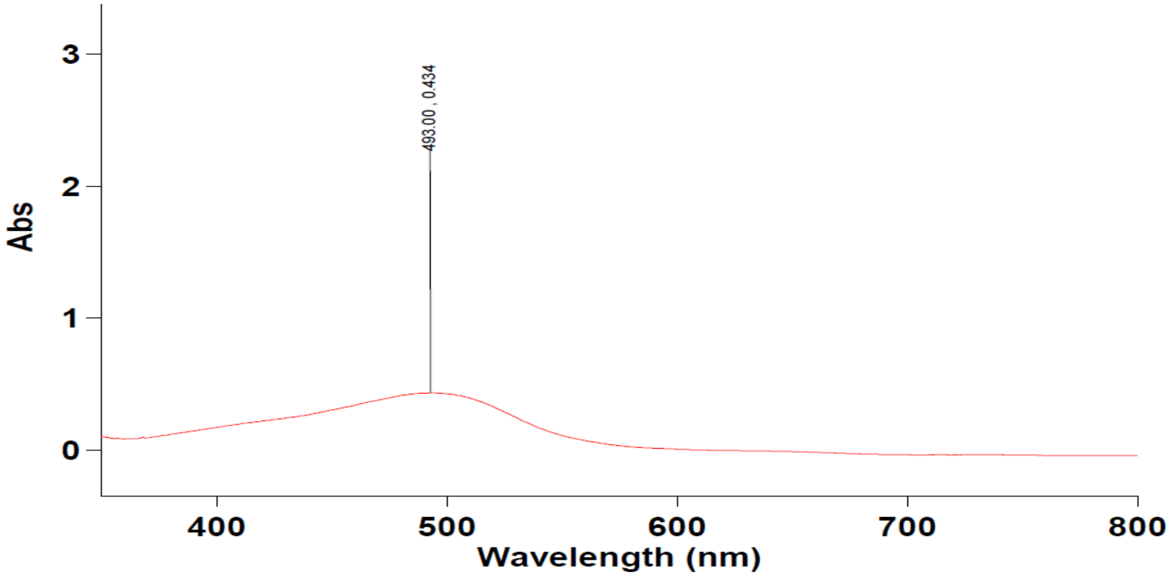

Figure 1: UV-Visible Absorbance of Bi-Herbal Dye Extract

The FTIR peaks observed with the corresponding group present for the bi-herbal dye extract are shown in Table 3.

Table 3: FT-IR Analysis

Wave number (cm^{-1})	Assigned vibration(s)	Functional group(s)
3619.2	O-H stretching (sharp, free)	Free (non H-bonded) phenolic O-H or isolated alcohol O-H
3399.3	O-H / N-H stretching (broad)	H-bonded alcohols/phenols and/or N–H of amines/amides
3082.5	=C–H stretching	Aromatic =C-H or =C-H of alkenes
2109.7	C≡C or C≡N stretching (or combination/overtone)	Terminal/internal alkyne or nitrile (less likely), or combination band
1923.3	Overtone / combination band or conjugated carbonyl-related	Possible carbonyl overtone or weak conjugation-related band
1798.6	C=O stretching (high frequency)	Anhydride, γ-lactone, or highly strained/ conjugated ester carbonyl
1595.3	C=C aromatic ring stretching	Aromatic ring vibrations (aromatic C=C)
1517.0	Aromatic C=C / N–O asymmetric stretch	Aromatic ring vibrations; could also correspond to NO_2 asymmetric if nitro present

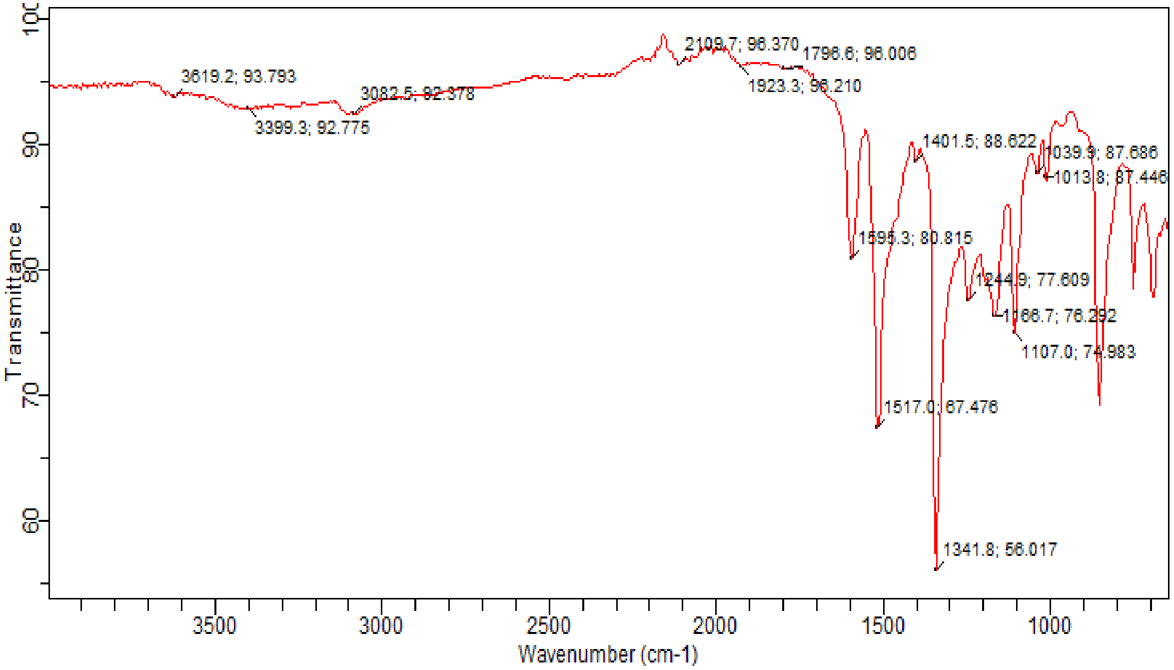

Figure 2: FT-IR Spectra of Bi-Herbal Dye Extract

The wash fastness test results obtained using I.S.O 3 Standard for the dyed substrate are shown in Table 4

Table 4: Wash Fastness

/No	Sample	Change in colour	Staining of adjacent fabric	Colour of dyed fabric
1	Bi-herbal extract + copper sulfate	3/4	3	Lemon green
2	Bi-herbal extract + Zinc sulfate	4	4	Yellow

Change in shade	**Staining**
5 = Excellent	5 = no staining
4 = Very good	4 = very slight staining
3 = Good	3 = moderate staining
2 = fair	2 = significant staining
1 = poor	1 = deep staining

The light fastness test results obtained using 8 Blue Wool Standards for the dyed substrates are shown in Table 5.

Table 5: Light Fastness

S/No	Sample	Changed in colour on nylon 6,6 fabric
1	Bi-herbal extract + copper sulfate	5
2	Bi-herbal extract + Zinc sulfate	6

Fastness rating	**Degree of fading**	**Fastness rating**	**Degree of fading**
8	none	4	appreciable
7	very slight	3	significant
6	slight	2	extensive
5	moderate	1	very extensive

The physical properties of the bi-herbal dye extracted from turmeric root and *Acacia nilotica* pods as shown in Table 1, indicate strong potential for application on nylon 6,6 fabric. The melting point range of 119-122 °C suggests the presence of thermally stable phytochemicals, which is desirable for dyeing processes that require moderate heating. The percentage yield of 48% shows that the extraction method was efficient, reflecting the high concentration of curcuminoids in turmeric and tannins in *Acacia*, which are known to produce substantial quantities of colorants [8]. The dark brown appearance confirms successful extraction and concentration of chromophoric compounds, consistent with earlier reports that combining phenolic-rich botanicals enhances pigment intensity [9].

The UV-Visible spectrum (nm) (Figure 1), of the bi-herbal dye extract as presented in Table 2, showed a notable absorption peak at 493 nm, indicating the presence of conjugated polyphenolics such as flavonoids, tannins, and curcuminoids. Absorption around 480–500 nm has been previously reported for turmeric pigments and other polyphenolic dyes [10] which shows that the absorption at 493 nm confirms the presence of conjugated chromophores such as curcuminoids and tannins, responsible for colour formation.

The IR spectrum (IR v_{max} cm^{-1}) (Figure 2), as summarized in Table 3, revealed broad O-H stretching bands around 3399 cm^{-1} and a sharper signal at 3619 cm^{-1}, confirming the presence of phenolic and alcoholic groups features commonly found in natural dye molecules. Aromatic C=C stretching bands at 1595 and 1517 cm^{-1} further indicate the presence of aromatic rings typical of curcuminoids and tannins, consistent with earlier FT-IR characterizations of turmeric and *Acacia* extracts [11].

The wash fastness results showed that both mordanted samples exhibited moderate resistance to washing, with zinc sulfate performing better than copper sulfate. The copper sulfate mordanted dyed substrate recorded colour change and staining ratings of 3/4 and 3, respectively, indicating partial dye loss during washing. In contrast, the zinc sulfate mordanted dyed nylon 6, 6 fabric achieved ratings of 4 for both parameters, suggesting stronger dye-fiber bonding. These findings agree with earlier studies which reported that zinc salts improve wash fastness by forming more stable coordination complexes with dye molecules on polyamide fabrics [12].

The light fastness results also showed superior performance of zinc sulfate mordanted samples compared to copper sulfate. The copper sulfate treated fabric recorded a light fastness rating of 5, showing good resistance to fading, while the zinc sulfate mordanted sample achieved a rating of 6, indicating very good stability under light exposure. These observations correlate with previous findings that zinc mordants enhance photostability by reducing photo-oxidation of the dye-fiber complex.

CONCLUSION

The study demonstrated that bi-herbal dyes from turmeric roots and *Acacia nilotica pods* are effective for dyeing Nylon 6,6 fabric. The dye system exhibited good spectral properties, satisfactory fastness, and improved performance with zinc mordant. Turmeric provides chromophoric intensity, while tannins from *Acacia nilotica* improve binding and fastness. Zinc sulfate mordant forms stronger coordination complexes with dye molecules and Nylon 6,6, resulting in superior wash and light fastness compared to copper sulfate. This confirms its potential as a sustainable alternative to synthetic dyes in textile applications.

Recommendations

1. Explore eco-friendly mordants such as alum and plant-based mordants
2. Optimize dye concentration and temperature conditions
3. Investigate antimicrobial and UV-protection properties

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