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INVESTIGATING THE FEASIBILITY OF UTILIZING *PENNISETUM PURPUREUM* LEAVES WASTE AS A SUSTAINABLE DYE: EXTRACTION, CHARACTERIZATION AND APPLICATION ON TEXTILE

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ABSTRACT

This study investigated the potential of Pennisetum purpureum (Elephant grass) leaves waste as a source of natural dyes. The objective was to extract, characterize and apply the natural dyes on textile fabrics. Elephant grass was chosen due to its abundant availability as agricultural waste, making it an environmentally sustainable alternative to synthetic dyes. The extraction process involved maceration, followed by filtration to obtain the dye extract. The dye components were isolated using vacuum liquid chromatography and then characterized using analytical tools such as UV-Visible Spectrophotometry, High-Performance Liquid Chromatography (HPLC) and Fourier-Transform Infrared Spectroscopy (FTIR) to identify the presence of specific compounds responsible for the dyeing potential. The perspiration fastness, rubbing fastness, light fastness and wash fastness properties were assessed to evaluate the durability and suitability of the natural dyes. The UV-Visible spectrum, HPLC and FTIR analysis confirmed the presence of chromophores such as conjugated systems, and provided information about chemical components namely rutin, quercetin, senecionine, hyoscyamine and tannic acid present in the dye, as well as the types of bond present in the molecules including C-H, O-H, C=O and C-O groups, which are characteristics of natural dyes. The dyed textile fabrics demonstrated somewhat fair to good with a rating of 3-7 for perspiration fastness, light fastness, rubbing fastness and wash fastness, indicating the potential of the natural dye for practical applications. The findings can inspire further research and development in utilizing agricultural waste for natural dye production, promoting sustainable practices in textile manufacturing.

Keywords: Natural dye, Characterization, Maceration, Isolation, *Pennisetum purpureum*, Leaves, Waste, Textile

INTRODUCTION

In recent years, there has been growing interest in finding sustainable and eco-friendly alternatives in various industries, including the textile industry. The textile industry is notorious for its heavy reliance on synthetic dyes, which not only contribute to environmental pollution but also have detrimental effects on human health (Maleki and Barani, 2019). In response to these concerns, researchers have focused their

efforts on exploring natural dye sources that are environmentally sustainable and offer viable alternatives to synthetic dyes (Maleki and Barani, 2019).

One such potential natural dye source is *Pennisetum purpureum* (Elephant grass) leaves waste. *Pennisetum purpureum* (Schumach), commonly referred to as elephant grass, is a tall and fast-growing perennial grass that belongs to the Poaceae family (Jack *et al.,* 2020). It is widely cultivated in tropical and subtropical regions as a weed or forage crop (Obi *et al.,* 2008). Due to its extensive cultivation, the leaves of *Pennisetum purpureum* (elephant grass) are abundantly available as agricultural waste. This waste material presents an opportunity to explore its potential for extracting natural dyes, thereby offering a sustainable and economically viable solution.

This study explored the potential of *Pennisetum purpureum* leaves (Elephant grass) waste as a source of natural dye and its application in dyeing textile fabrics. The colouring matters identified in natural dyes include several classes of compounds such as tannins, alkaloids, anthraquinones, naphthoquinones and carotenoids. Due to the relatively low exhaustion of natural dyes, mordants are usually employed to improve the colour strength and fastness, and to obtain multiple shades (UI-Islam *et al.,* 2018; Adeel *et al.,* 2018; Barani, 2018). By investigating the extraction, characterization and application of natural dyes derived from *Pennisetum purpureum* leaves waste, this research endeavours to contribute to the development of sustainable and eco-friendly dyeing practices.

MATERIALS AND METHODS

Chemicals and Reagents

Laboratory grade ferrous sulphate ($FeSO_4$) was used as mordant while a diluted solution (2 g/L) of sodium carbonate (Na_2CO_3) was used to adjust the pH of the dye solution to 7. Reference detergent A soap (5 g/L) was used for the wash fastness test. *n*-Hexane, ethyl acetate, ethanol, hydrochloric acid (37% fuming HCl), acetonitrile, glacial acetic acid, Wagner's reagent (potassium iodide and iodine crystal) and sulfuric acid, all of which were of analytical grade and obtained from Merck (Darmstadt, Germany).

Plant Material

Pennisetum purpureum leaves were collected from Umuola-Egbelu, Abia State. The leaves were then identified and given a voucher number (No. 0615) from the Department of Forestry and Wood Technology at the Federal University of Technology, Akure. The leaves were washed with distilled water without squeezing to remove debris and dust particles, and then sun-dried for 3 weeks to retain the vibrant colours as the sun's energy aids in preserving the natural pigment. Once completely dried, the plant material was pulverized into a powder, using a manual blender (Porkert Manual Grinder No. 32) and stored at room temperature until further use.

Extraction of Crude Dyes

The dried powdered sample (500 g) of *Pennisetum purpureum leaves* were macerated with 2.0 L of dichloromethane (DCM) in an aspiratory bottle. This mixture was left at room temperature for 72 hours and stirred regularly. Afterward, the resulting extract was filtered into a conical flask using a funnel and filter paper to obtain the dichloromethane extract. The residue left was again subjected to a second extraction with fresh DCM according to the procedure described above to obtain the second extract of DCM, this procedure was repeated three (3) times in total to ensure thorough extraction of the leaves components (Figure 1).

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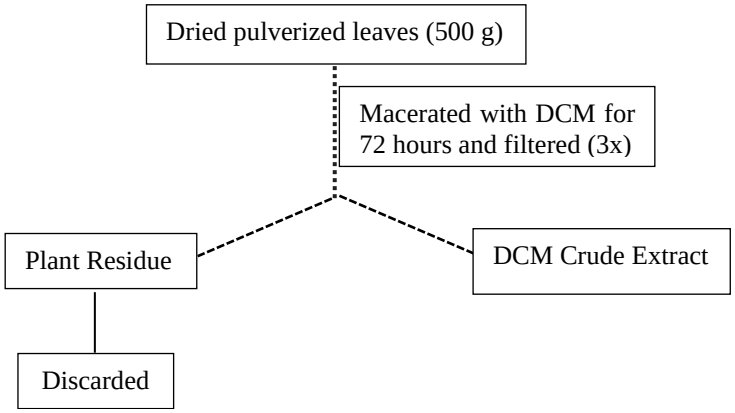

Figure 1: Extraction Procedure

Isolation and Purification of Crude Dyes

Vacuum liquid chromatography (VLC) was performed using the method described by Paranagama (2016) and Ndukwe *et al.* (2020) with slight modifications (Figure 2). To ensure optimal packing density, the VLC column was dry packed with thin layer chromatography (TLC) grade silica under vacuum. Subsequently, dichloromethane crude extract of *Pennisetum purpureum leaves* was prepared, along with silica gel mesh, and loaded onto the column. The elution process was carried out by sequentially using 300 ml of suitable solvent mixtures (mobile phase), beginning with a low polarity solvent (100 % *n*-hexane); subsequently, the polarity was gradually increased by adjusting the solvent ratio (*n*-hexane-DCM in ratios of 3:1, 2:2, 1:3), 100% DCM, DCM-ethyl acetate (3:1, 2:2, 1:3), 100 % ethyl acetate, ethyl acetate-EtOH (3:1, 2:2, 1:3) and 100 % EtOH) between each fraction collected. The column was pulled dry after each mobile phase to ensure proper separation.

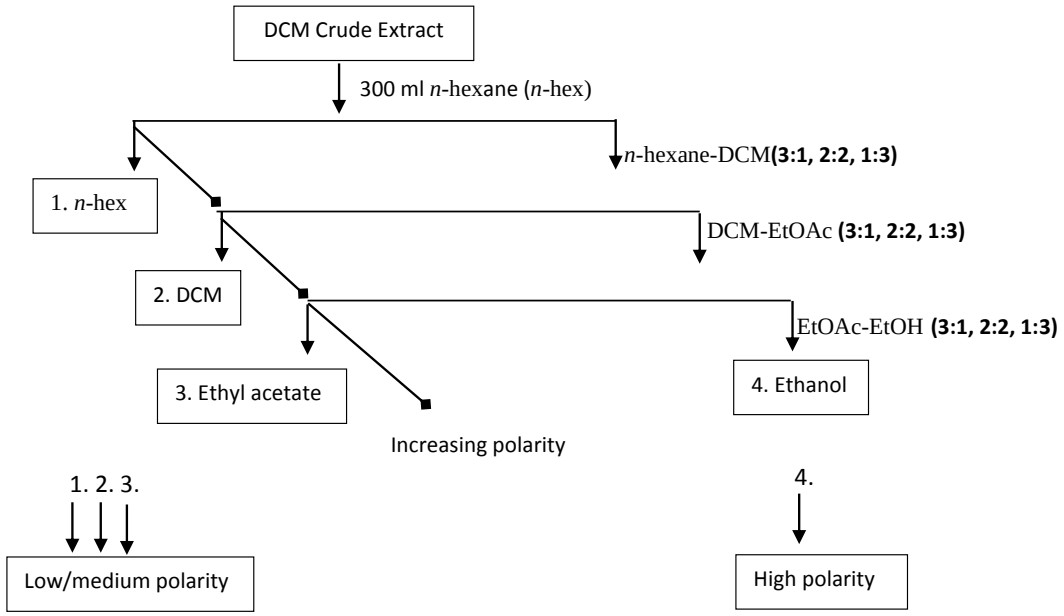

Figure 2: Framework of VLC model

Phytochemical Screening Tests

Phytochemical examination was conducted on the dye extract of *P. purpureum* leaves using standard procedures (Jack *et al.*, 2020; Clark and Omo-Udoyo, 2021) to detect the following bioactive compounds: alkaloids,

flavonoids, glycosides, terpenoids, tannins and steroids.

Characterization of the Isolated Dye

Properties of a spectrum are examined and understood through a scientific process known as spectra characterization. The chemical composition and properties of dye from *Pennisetum purpureum* leaves were analyzed and interpreted by utilizing HPLC, FTIR and UV-vis scanning techniques. This process yields valuable information essential for evaluating their potential as a sustainable dye.

UV-Visible Analysis

A UV-VIS-NIR scanning spectrophotometer UV-3101PC (SHIMADZU) was used for all spectrophotometric measurements. All measurements were carried out using quartz cells 10-mm at room temperature (25±2 ℃) and changes in their absorption (400-800 nm) were noted.

Fourier Transform-Infrared Analysis

The software used for FTIR data collection was the Infrared Data Management (IRDM) system. The infrared spectrum was recorded at room temperature with a PerkinElmer Fourier Transform Infrared Spectrometer, Model spectra 100 series (Perkin-Elmer Corporation, Norwalk, CT, USA), equipped with a deuterated triglycine sulfate (DTGS) detector and controlled by a Perkin-Elmer PC. The instruments were maintained in constant humidity to minimize water vapor interference.

Drops from each standard were placed on the attenuated total reflection element and scanned. After each scan, the ATR diamond was rinsed three times with acetone and dried with soft tissue before adding the sample; Calibration spectrum was obtained from 64 scans at a resolution of 2 cm^{-1} with strong apodization through 3500-1000 cm^{-1} frequency region. The spectrum was rationed against the background air spectrum. All the scans were done in triplicate with the spectrum recorded as absorbance and stored on a disk.

High Performance Liquid Chromatography Analysis

The HPLC analysis was carried out using AGILENT 1260 infinity HPLC system with a photo diode array detector (Agilent Technologies, Palo Alto, CA). The chromatographic separations were carried out using an Xbridge^{TM} Shield RP_{18} column (4.6 mm I.D. × 150 mm, 3.5µm) (Waters, Milford USA), with column oven temperature maintained at 20 ℃ (Park *et al*., 2016). The mobile phase consisted of 0.1% acetic acid (Solvent A) and 100 % acetonitrile (Solvent B). The mobile phase flow rate was 1.0 ml/min with gradient elution. The percentage composition of Solvent B was maintained at 20 % for 3 min, gradually increased to 38% for 24 min, further increased to 90 % for 1 min and maintained at 90 % for 5 min, which was followed by equilibration to the initial composition for 6 min. the injection volume was 10 µL and UV absorbance was monitored at 365 nm.

Mordanting

In this experiment, the process of mordanting was conducted before dyeing, referred to as pre-mordanting. The aim of pre-mordanting was to enhance the adsorption of the dye and ensure a strong bond between the dye and the fabric. The commonly used mordant, such as iron (ferrous sulfate) was selected. Initially, the cotton fabric was immersed in warm water (approximately 46 ℃) for 30 minutes to relax the fabrics, which would make the fabric more receptive to mordanting and dyeing. Subsequently, the specific mordanting procedure was carried out based on the information found in the literature (Feng *et al.,* 2007).

Dyeing Procedure

The dyeing procedures were performed in accordance with the general dyeing method (Baaka *et al.,* 2015). A fabric-to-dye ratio of

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1:10 was chosen based on the weight of the fresh natural dyes extracted and the fabrics used in the experiment. The fabric was immersed in a dyebath composed of 0.25% aqueous solution of the dye. The dye liquor ratio of 1:40 was kept constant for all samples, and the pH value of the dyebath was optimized depending on the type of raw material. For *P. pupureum*, the pH values were adjusted by adding drops of sodium hydroxide or hydrochloric acid to achieve pH levels of 9-10 and 3-4, respectively. The temperature of the dyebath was gradually increased (about 1 ℃) until it reached 100 ℃ and was kept at this temperature for about 60 minutes. Afterwards, the dyebath was allowed to cool to around 60 ℃. The dyed fabric was then squeezed, thoroughly rinsed with water and air-dried.

Determination of Wash Fastness

The dyed specimens of wool and nylon fabrics with a dimension of 5 cm × 4 cm were placed between two pieces of undyed white fabrics of the same dimension. Three pieces were stitched together around the edges to create a composite specimen. The composite specimen was agitated with ten steel balls in a 100 ml beaker, containing a solution made-up of 5 g/L soap and 2 g/L soda ash with a liquor ratio of 1:50 as stipulated by ISO 3 standards. The washing process was carried out at 60 ± 2 ℃ for a duration of 30 minutes in a launder-o-meter. The composite specimen was then rinsed, separated and dried. The change in colour of the test samples and the staining of the adjacent undyed white fabrics were evaluated using the grey scale, with references to the ISO 9001 2000 group.

Determination of the Light Fastness

Strips of the fabrics and the blue wool standards were cut and mounted on cardboard paper. Half portions of the specimens were covered to obstruct the light source from getting to that portion. The specimens were exposed to natural daylight in a south-facing direction at an angle of 45 ºC, sloping from the horizontal, for a duration of 72 hours. After 72 hours, the specimens were removed and the extent of their fading was assessed by comparing them to the blue wool standards.

Determination of Fastness to Dry and Wet Rubbing

The dyed samples' dry and wet rubbing fastness was tested using a Crock meter in accordance with ISO 105-X 12:2001 standards. The specimen was placed in the Crock meter and a piece of standard white cloth (starch free 96.100 cotton fabric of a long type) was used to rub against the coloured specimen. This rubbing process was carried out under controlled conditions of pressure and speed. For both the dry and wet tests, the rubbing fingers were covered with white cloth and moved back and forth for a total of 20 rubbing strokes. The colour transferred onto the white cloth was compared with a Grayscale for alteration of colour, consisting of grades 1-8.

Fastness to Perspiration Test

The fastness to perspiration test evaluates the ability of textile fabrics to resist colour fading or running when exposed to perspiration. This test was conducted using acidic and alkaline solutions; the acidic solution consists of sodium chloride (NaCl, 5 g/L), disodium hydrogen orthophosphate dehydrate (Na_2HPO_4 2.5 g/L) and histidine monohydrochloride monohydrate. The pH of the solution was adjusted to 5.5 while the alkaline solution consists of $C_6H_9O_2N_3.HCl.H_2O$ (0.5 g/l) and is adjusted to pH 8 using 0.1 N sodium hydroxide (NaOH). The liquor ratio for the test was 20:1.

RESULTS AND DISCUSSION

Phytochemicals of the Isolated Dye

The crude dye extracted from *P. pupureum* leaves using the maceration method were analyzed to identify specific compounds. Previous research conducted by Hayouni *et al.* (2007) suggested that the maceration method may be more effective for extracting secondary metabolites. The crude

dichloromethane extract was separated into thirteen (13) fractions using vacuum liquid chromatography. Remarkably, one of the fractions exhibited the presence of metabolites such as tannins, flavonoids, steroids and alkaloids. However, cardiac glycoside and terpenoid were not observed (as indicated in Table 1). Interestingly, these findings align with a prior investigation by Adeoye (2021), who also reported the absence of these compounds (cardiac glycoside and terpenoid) in the leaves of the same plant species. Therefore, the active fraction containing tannins, flavonoids and alkaloids are of relevance to the dye industry because of their potential applications. Tannins are known for their astringent properties and ability to form complexes with metal ions, making them useful in dyeing processes (Janani and Winifred, 2013). Flavonoids on the other hand are recognized for their therapeutic potential and possesses antimicrobial and antioxidant properties (Ndukwe *et al.,* 2020). While their direct application in the dye industry may be limited, their antioxidant properties can be valuable for the preservation of natural dyes and pigments. Some alkaloids have been used as natural dyes in the past, but their application in modern dyeing processes is limited. However, they may still have niche applications in natural dyeing processes (Rather *et al.,* 2017).

Table 1: Phytochemical groups present in the Isolated Dye

Phytochemical group	VLC Fraction 13 (Isolated Dye)
Alkaloids	+
Steroids	+
Tannins	+
Flavonoids	+
Terpenoids	-
Cardiac Glycosides	-

KEY: + Present, - Absent

Chemical Characteristics and Composition of the Isolated Dye

The UV-visible wavelength of *P. purpureum* leaves dye is shown in the first column of Table 2. The wavelength at 401 nm is attributed to a $\pi \rightarrow \pi^*$ transition resulting from the presence of multiple conjugated bonds and Figure 3 represented a plot of the absorbance versus wavelength. The absorption peak observed in this study aligns with the research of Budidha *et al.* (2020). In their findings, they have associated the absorption peak of 401 nm with the 8^{th} harmonic of O-H stretching vibrational bands. This information is valuable as it provides additional insight into the molecular structure and other pertinent details of the dye. The colour associated with this absorption peak falls within the violet region of the light spectrum, and its complementary colour was yellow.

FT-IR spectroscopy has been widely used for the analysis of natural dyes (Amir-Al Zumahi *et al.,* 2020). The dye extracted using dichloromethane exhibits distinct bands within different segments of a spectrum: 3600-3200 cm^{-1}, 3100-2800 cm^{-1}, 1650-1600 cm^{-1}, 1480-1300 cm^{-1} and 1300-900 cm^{-1} as shown in Table 2. These bands signify the stretching vibrations of various functional groups, such as O-H, C-H, C-C, C=C, C=O, aromatics, and nitrile. Several studies conducted by different researchers (Ezeokonkwo *et al.,* 2018 and Sofyan *et al.,* 2018) have extensively discussed and identified the functional groups corresponding to the different specific segments of the FT-IR spectrum.

The spectrum for the *P. purpureum* leaf dye as represented in Figure 4 provides valuable insights into its chemical composition. This data was obtained within the frequency range

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of 3500 – 1000 cm^{-1}, enabling the analysis of the dye molecular structures and functional groups. The spectrum revealed several peaks at specific wavenumbers, including 3257.7 cm^{-1}, 2094.8 cm^{-1}, 1636.3 cm^{-1} and 1390.3 cm^{-1}. These peaks indicated the presence of compounds responsible for the colouring properties of the dye. Notably, within the range of 1700 to 1100 cm^{-1}, the absorption bands exhibited similarities to the characteristic values associated with flavonoid-like dye compounds, as reported by Jemo and Parac-Osterman (2017). The characteristics of *P. purpureum* leaf dye can be observed through stretching vibrations at 3257.7 cm^{-1}, which indicates the presence of O-H in phenol, as suggested by Al-Sharairi *et al.* (2020). According to Kassim *et al.* (2011), the shape of the OH-stretching band provides preliminary information on the occurrence of a polymerization process. Condensed tannins, which have varying degrees of polymerization, display a broad range of peaks ranging from 3,700 to 3,000 cm^{-1}.

The overview of flavonoids detected in the isolated dye (Table 3 and Figure 5) revealed that Rutin had the highest percentage composition and affinity for the stationary phase, with values of 51.6% and 10.508 minutes, respectively. Isoquercetin followed with a value of 38. 8% and 8.536 minutes. On the other hand, quercetin had the lowest retention time and percentage composition with a value of 7.095 and 9.63%. These findings align with the research conducted by Engida *et al.* (2013) who also identified rutin and quercetin as the main flavonoid colourants in their study. However, Table 3 and Figure 6 illustrate the presence of tannins in *P. purpureum* leaf dye. Tannic acid was the sole compound detected in the isolated dye with concentration, retention time and percentage composition of 16.5350 µg/ml 3.1099 minutes and 100%. The presence of tannic acid, a recognized natural mordant, is crucial for enhancing the colour fastness of dyes (Janani and Winifred, 2013). In addition, Table 3 and Figure 7 depict the alkaloids identified in the isolated dye; atropine (RT 3.757 minutes) was observed to be the most prominent alkaloid with a percentage composition of 64.6%, followed by hyoscyamine (RT 4.438 minutes) as the second most prevalent alkaloid with a value of 21.5%. Conversely, senecionine (RT 7.299 minutes) exhibited a comparatively low percentage composition (3.9%). However, the striking observation was that comparisons with the existing literature on *P. purpureum* leaves were not currently feasible since this study represents the first attempt to identify these compounds using HPLC.

Table 2: Spectra data of the isolated dye

UV-visible (nm)	Infrared (cm^{-1})
401.00 ($\pi \rightarrow \pi^*$)	3257 (O-H of phenol)
	2095 (C-H stretch in aromatic)
	1610-1440 (C=C stretch of aromatics)
	260-1000 (C-O stretch in phenols)

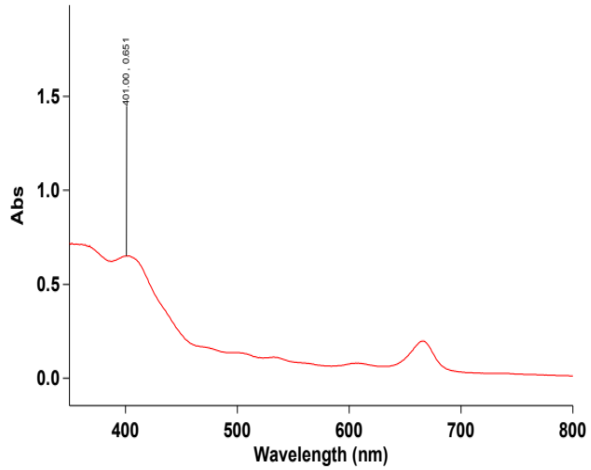

Figure 3: UV-visible spectrum of the dye

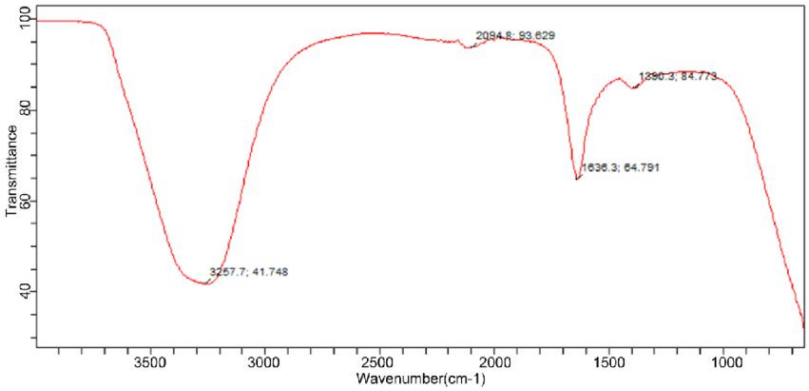

Figure 4: FTIR spectrum of the isolated dye

Table 3: Constituents of the dye Isolated from *P. purpureum* leaves

Compound	Phytochemical Group	Concentration (µg/ml)	Percentage composition per Group
Isoquercetin (**1**)	Flavonoids	44. 096	38.8
Rutin (**2**)	Flavonoids	58.641	51.6
Quercetin acid (**3**)	Flavonoids	10.953	9.63
Tannic acid (**4**)	Tannins	16.5350	100
Senecionine (**5**)	Alkaloids	19. 147	13.9
Hyoscyamine (**6**)	Alkaloids	29.631	21.5
Atropine (**7**)	Alkaloids	89.095	64.6

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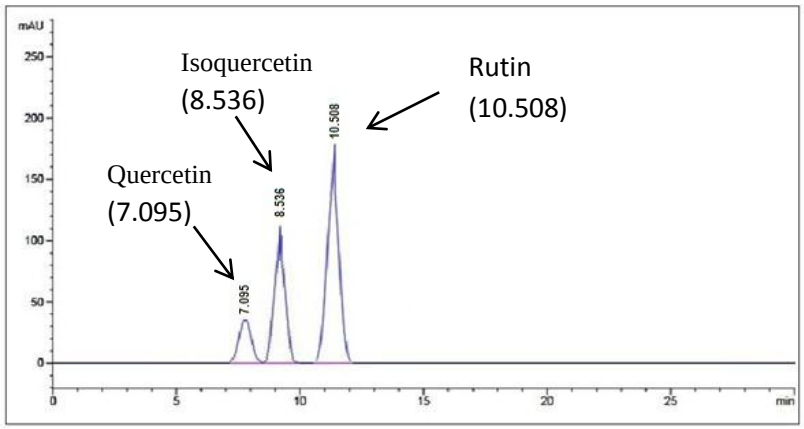


Figure 5: HPLC chromatogram of flavonoids present in the isolated dye

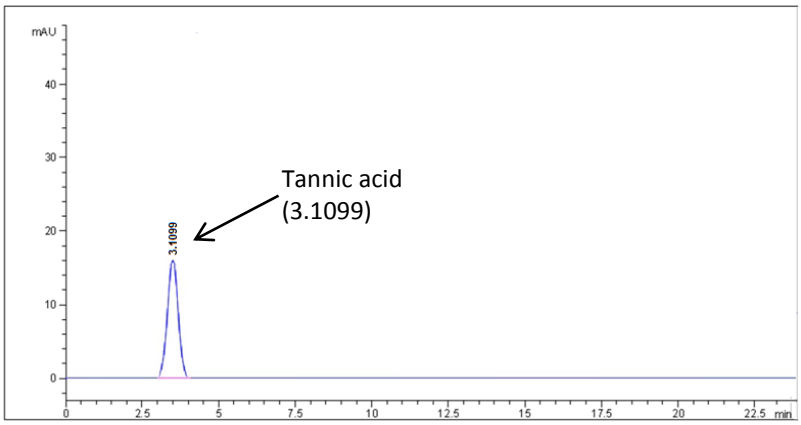


Figure 6: HPLC chromatogram of tannins present in the isolated dye

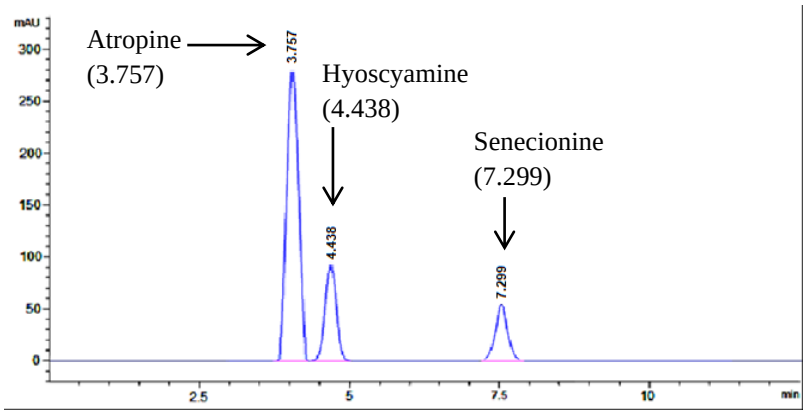
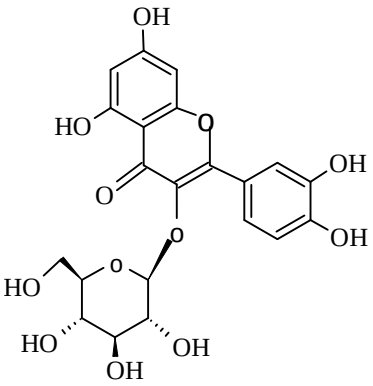


Figure 7: HPLC chromatogram of alkaloids present in the isolated dye



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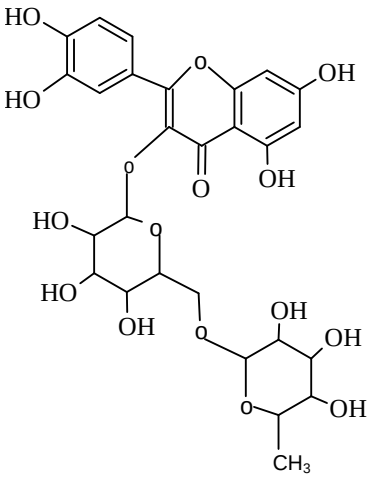

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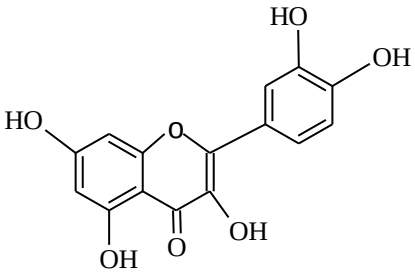

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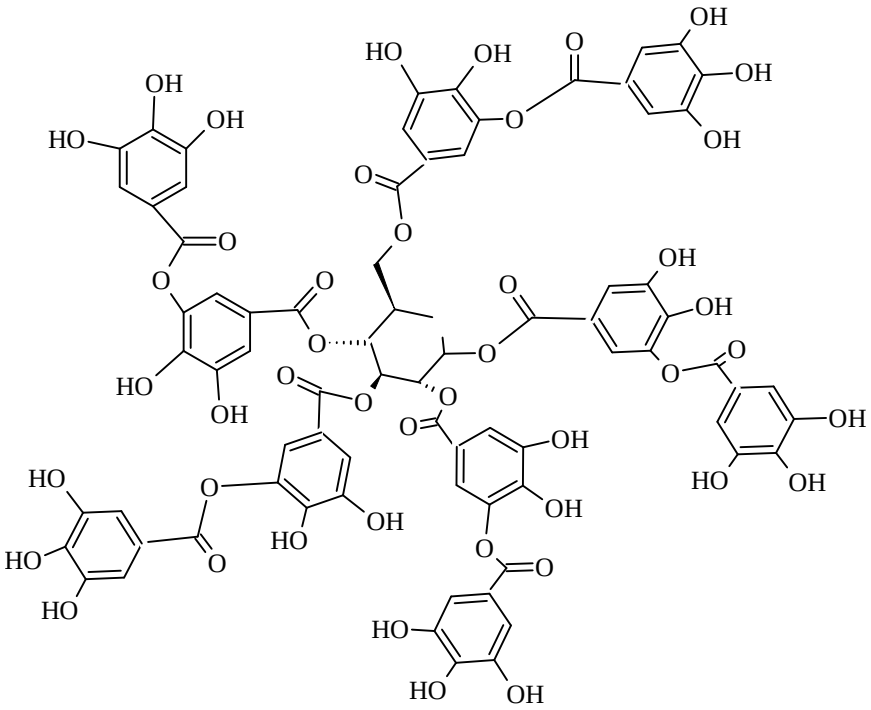

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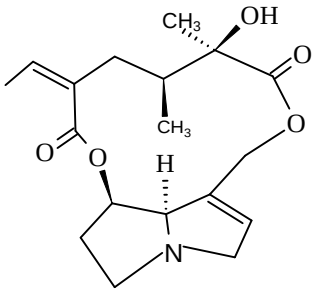

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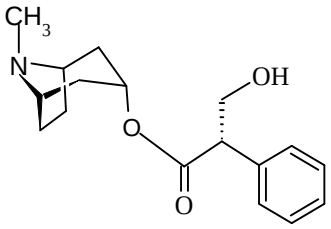

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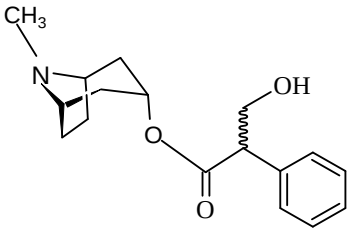

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Colour Fastness Properties

This study reports on the fastness properties, including light fastness, perspiration fastness, wash fastness and rubbing fastness, of fabrics dyed with *P. purpureum* leaf dye.

Colour Fastness to Washing

Wash fastness of dye was influenced by the rate of diffusion of dye and the state of dye inside the fabric (Kanchana *et al.,* 2013). The results presented in Table 4, Figures 8 and 9 demonstrate that the fabrics dyed with *P. purpureum* leaves dye exhibited somewhat fair to good colour fastness, ranging from DF 2% to DF 8%. However, when examining the specific cases of wool and nylon fabrics dyed with DF 4%, they received the lowest rating of 2-3/3. This rating indicates that there was a minimal colour change in the fabrics after washing. Despite the deep shade of the fabrics dyed with DF 4%, it did not receive a high rating on the scale. This could be attributed to the presence of smaller dye-metal complexes and weaker interaction between the dye and the fabric, making it easier for the dye to wash out or diffuse from the fabrics and ultimately leading to its poor rating on the scale.

Colour Fastness to Light

A Colour fastness test was conducted on the dyed fabrics to evaluate their resistance to daylight exposure. Overall, the samples exhibited good to excellent fastness to light, with ratings ranging from 5-7. However, DF 2 % nylon received a lower rating of 3 on the blue wool scale after 48 hours exposure to simulated sunlight (Table 5, Figures 8 and 9). This indicates that nylon and wool fabrics can be effectively dyed using *P. purpureum* leaves dye. The presence of flavonoids in *P. purpureum* leaves, as mentioned by Adeoye (2021), may be responsible for this successful dyeing process. Flavonoids are phenolic compounds that can form hydrogen bonds with carboxyl groups present in protein fibers such as wool (Agarwal and Patel, 2002). Additionally, Burkinshaw and Kumar (2009) suggested that the characteristics of mordants like ferrous sulfate play a more significant role in determining the fastness properties of natural dyes than the dyes themselves. The obtained dye and their properties are the result of the formation of wool mordant dye interactions (Figure 10).

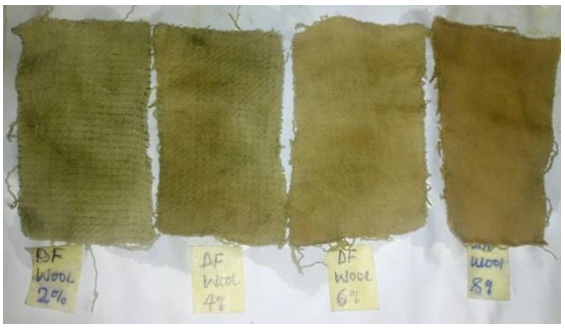

Figure 8: Wool fabrics dyed with the isolated dye and tested for colour fastness

Figure 9: Nylon fabrics dyed with the isolated dye and tested for colour fastness

Table 4: Colour fastness to wash

Sample Code	Colour Change	
	Wool	Nylon
DF 2 %	3	4
DF 4 %	2-3	3
DF 6 %	3	4
DF 8 %	4-5	3-4

Key: DF-Dye concentration, 1-very poor, 2-poor, 3-fair, 4-moderate, 5-good, 6-very good, 7-excellent, 8-outstanding

Table 5: Colour fastness to light

Sample code	Colour Change	
	Wool	Nylon
DF 2 %	6	3
DF 4 %	5	5
DF 6 %	7	6
DF 8 %	5	6

Key: DF-Dye concentration, 1-very poor, 2-poor, 3-fair, 4-moderate, 5-good, 6-very good, 7-excellent, 8-outstanding

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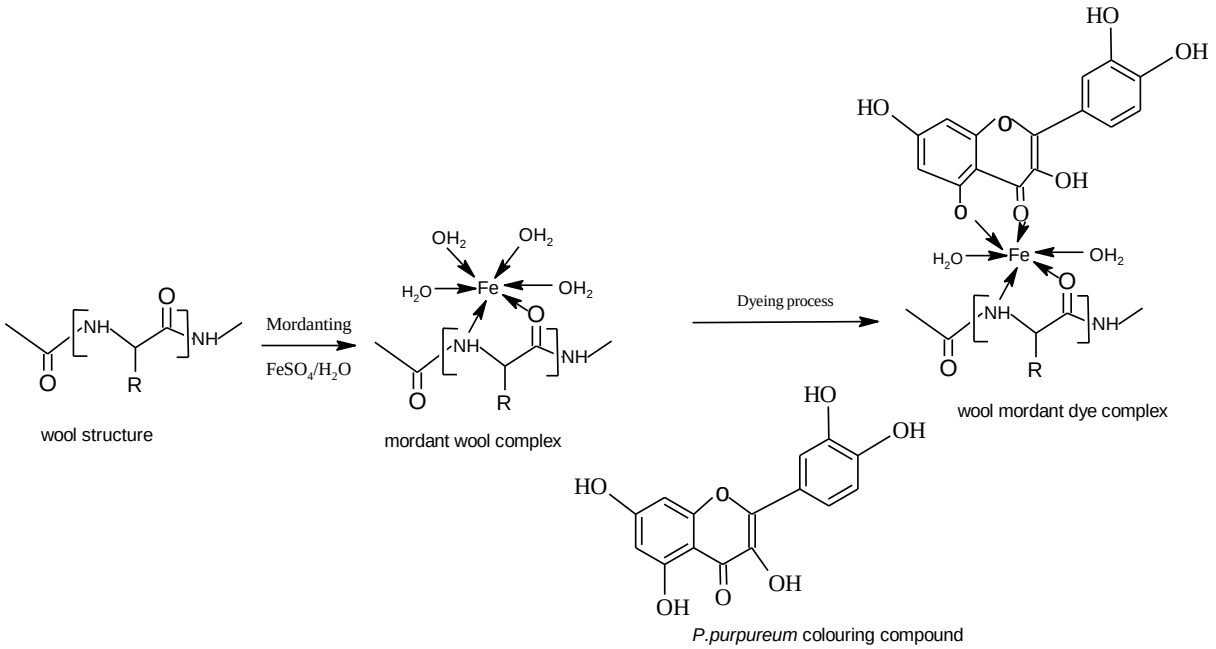

Figure 10: Schematic representation of wool-mordant-dye interaction

Colour Fastness to Perspiration

The perspiration fastness of nylon and wool fabrics dyed with the isolated dye was evaluated under acidic and alkali conditions, as shown in Table 6 and Figures 8 and 9. The fabrics (mordanted with ferrous sulfate) had moderate fastness to alkali perspiration at 6% and 8% dye concentrations for both nylon and wool. The fabrics also showed fair to moderate fastness to acidic perspiration at 2% and 4% dye concentrations for both nylon and wool, with very light staining on adjacent fabrics. These results indicate that the alkali extract of *P. purpureum* leaves dye can produce fabrics that are resistant to perspiration in different environments.

Colour Fastness to Rubbing

The rubbing fastness results for nylon and wool dyed with isolated dye from *P. purpureum* leaves extract at concentrations ranging from DF 2% to DF 8 % revealed that the use of ferrous sulfate as a mordant resulted in a rating of 5 for dry rubbing and a rating of 4 for wet rubbing at DF 8 % concentration on nylon, which was better than its performance on wool (Table 7 and Figures 8 and 9). Comparatively, the results indicated that the dry rubbing performance for both wool and nylon was superior to their wet rubbing performance.

Table 6: Colour fastness to perspiration

Sample code	Colour Change			
	Wool		Nylon	
	Acid	Alkaline	Acid	Alkaline
DF 2 %	3	2-3	3	3
DF 4 %	4	3-4	4	3-4
DF 6 %	2-3	4	3-4	4
DF 8 %	4	4	3	4

Key: DF-Dye concentration, 1-very poor, 2-poor, 3-fair, 4-moderate, 5-good, 6-very good, 7-excellent, 8-outstanding

Table 7: Colour fastness to rubbing

Sample Code	Wool		Nylon	
	Dry rubbing	Wet rubbing	Dry rubbing	Wet rubbing
DF 2 %	4	3	4	2-3
DF 4 %	3	3	3-4	4
DF 6 %	3	4	4	3-4
DF 8 %	4	3-4	5	4

Key: DF-Dye concentration, 1-very poor, 2-poor, 3-fair, 4-moderate, 5-good, 6-very good, 7-excellent, 8-outstanding

CONCLUSION

Extraction of natural dyes from *Pennisetum purpureum* (Elephant grass) leaves waste and characterization of the resulting dyes were effectively achieved. The application of this dye on textile fabrics, specifically nylon and wool, demonstrated promising results especially in terms of colour fastness to light. The fabric samples treated with the dye showed moderate to fair levels of fastness to perspiration in both alkali and acidic conditions. This study has shown that *Pennisetum purpureum* leaves waste can be used as a green alternative for textile dyeing.

Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this manuscript.

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