

From Weeds to Wearables: Exploring Sustainable Textile Dyeing through Wildflower Pigments

¹ Asha M P and ² Dhvani S Kumar

¹ Assistant Professor, Department of Biosciences, Union Christian College, Aluva-2, Kerala, India

² Department of Biosciences, Union Christian College, Aluva-2, Kerala, India

ashamp@uccollege.edu.in

Abstract— The increasing environmental concerns of synthetic dyes have led to a renewed interest in natural dyes derived from plant sources. This study investigates the potential of weed flower petals, often considered waste flora, as a sustainable source of natural dyes for cotton fabric. Three different extraction methods were employed: Alkaline extraction (using dilute base to enhance pigment release), chloroform extraction (to isolate non-polar pigments), and aqueous extraction (using water as a solvent for eco-friendly processing). Each method yielded distinct pigment profiles, highlighting the influence of solvent polarity and extraction conditions on dye yield and quality. The extracted dyes were used to treat pre-mordanted cotton fabric using chemical mordants to improve dye fixation, color intensity, and wash fastness. The dyed samples were then analyzed using UV-Visible spectroscopy to characterize the pigment compounds present in each extract and to assess the optical absorbance across visible wavelengths. The results revealed notable differences in pigment concentration and stability among the three extraction methods, with acid and chloroform extractions showing higher pigment intensities compared to aqueous extraction. This research demonstrates the viability of utilizing weed flower petals as an eco-conscious dye source and emphasizes the role of extraction technique and mordant treatment in optimizing natural dye applications for textiles. The findings contribute to the field of sustainable textile development by promoting the use of locally available, biodegradable dye sources and green processing methods.

Index Terms— Natural dyes, weed flower petals, acid extraction, chloroform extraction, aqueous extraction, cotton fabric, mordant treatment, UV-Visible spectroscopy, dye fixation.

1. INTRODUCTION

The textile industry is one of the largest consumers of synthetic dyes, many of which are derived from petroleum-based chemicals. These dyes, though effective in producing vibrant and long-lasting colors, have raised significant environmental concerns due to their toxic and non-biodegradable nature [6]. The discharge of untreated dye effluents into water bodies causes significant ecological damage, including water pollution, bioaccumulation, and potential health risks to both aquatic life and humans [3].

As a response to these concerns, the demand for eco-friendly and sustainable alternatives has been steadily increasing. Natural dyes, which are derived from plant, animal, and mineral sources, offer a promising solution due to their biodegradability, non-toxicity, and renewability [1]. Among plant-based sources, weed flower petals represent a particularly valuable and underutilized resource. Weeds are abundant, grow rapidly without extensive cultivation, and are often treated as waste, making them a sustainable raw material for natural dye extraction [2].

The method of dye extraction significantly affects the color yield, stability, and application of natural dyes. Different solvents, such as water (aqueous extraction), dilute base (alkaline extraction), and organic solvents like chloroform (non-polar solvent extraction), are used to isolate pigment compounds based on their solubility and chemical nature [5]. Each extraction method can yield a unique profile of pigments, thereby influencing the final dyeing outcome.

In textile dyeing, mordanting is a crucial step that enhances the bonding between dye molecules and fabric fibers. Mordants, typically metal salts or natural agents, enhance color fastness and intensity, making natural dyes more suitable for commercial and domestic textile applications [4]. Cotton, being a natural cellulose fiber, requires effective mordanting for better uptake and retention of natural dyes.

This study aims to explore the dyeing potential of weed flower petals using three different extraction techniques: aqueous, alkaline, and chloroform. The extracted dyes are applied to mordanted cotton fabric, and the pigment composition is analyzed using UV-Visible spectroscopy. The results contribute to the advancement of sustainable textile processing and highlight the feasibility of converting floral waste into valuable natural dyes.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Plant Material: flower petals of selected weeds: *Antigonon leptopus* (Weed 1), *Ipomoea cairica* (Weed 2), and *Lantana camara* (Weed 3)

2.1.2 Solvents and Reagents:

Distilled water (for aqueous extraction), 1 % Sodium hydroxide for alkaline extraction, Chloroform (CHCl₃) for organic solvent extraction, Mordants: ferrous sulfate.

2.1.3 Textile Substrate: 100% pure cotton fabric (scoured and bleached)

2.1.4 Equipment: Hot plate with magnetic stirrer, UV-Visible spectrophotometer, Beakers, conical flasks, filter paper, glass rods, etc.

2.2 Methods: Dyeing of 100% cotton fabric with weed flowers is carried out at five stages: Extraction of dyes from flowers, Scouring, Mordanting (fixing dye with fiber), Dyeing and Drying. Extracted dyes were also subjected to analysis [34].

2.2.1 Extraction of Dye from Petals- Extraction of color dye was carried out by three different methods.

- i) Aqueous extraction method - 10 g fresh petals were boiled in 100 ml distilled water at 100°C for more than 60 minutes. Later, the decolorized petals were taken out of the extraction solvent. Filter the solution for further study.
- ii) Alkaline extraction method - In the alkaline extraction method, 10 g of fresh petals were boiled in 1% Sodium hydroxide for more than 60 minutes at 100 °c. The decolorized petals were taken out of the extraction solvent. Finally, filter the solution and use it for further study.
- iii) Chloroform Extraction method - In the alcoholic extraction method, 10 g of fresh petals were boiled in 50 % chloroform for more than 60 min. Filtrate was used for further study.

2.2.2 *Scouring of Cotton Cloth* -Cotton cloths used for dyeing were boiled in 10 % NaOH solution for 15 min [32].

2.2.3. *Mordanting* - The clean scouring cotton cloths were individually soaked with different mordents such as Ferrous Sulphate (FeSO₄) and then brought to a boil in the dye bath for about 30 minutes. The temperature of the dye bath was raised to 80°C for half an hour and left at that temperature for another 30 minutes. Mordanted cotton needs to be used immediately for dyeing because some mordants are very sensitive to light [34].

2.2.4. *Dyeing* - Transfer the treated cloth with mordant in the dyeing solution. Keep the dyeing solution containing the cloth pieces for more than 60 minutes in a boiling water bath.

2.2.5. *Drying* - The dyed material was washed with cold water and dried at room temperature in the open air.

2.2.6. *Analysis of Color Pigments from The Extraction*-

When the color strength of the extracted dye was determined in a spectrometer at 400nm and 660nm, it was found to have a broad spectrum.

3. RESULTS

3.1 Weed collection

Fresh flower petals of three different weed species were collected from local areas. The selection was made based on their availability and intense coloration, indicating high pigment potential. The collected weed species were *Antigonon leptopus* (Weed 1) (Fig. 5.1(a)), *Ipomoea cairica* (Weed 2) (Fig. 5.1 (b)), and *Lantana camara* (Weed 3) (Fig. 5.1 (c)).



Fig 3.1(a)
Antigonon leptopus (weed 1),



Fig 3.1 (b)
Ipomoea cairica (weed 2),



Fig 3.1 (c)
Lantana camara (weed 3)

3.2 Extraction Methods

Three extraction methods were used to obtain pigments from the weed petals:

Aqueous Extraction: Petals were crushed in distilled water, and the mixture was filtered to obtain the aqueous extract.

Alkaline Extraction: Petals were treated with an alkaline (1% NaOH) solution, then filtered to collect the extract.

Chloroform Extraction: Petals were crushed and extracted with chloroform, followed by filtration to collect the chloroform extract.



Fig 3.2 (a), different types of extraction of *Antigonon leptopus* (weed 1)



Figure 3.2 (b), different types of extraction of *Ipomoea cairica*.(weed 2)



Fig 3.2 (c), different types of extraction of *Lantana camara* (weed 3)

3.3 Scouring of Cotton Cloth

To remove starch and other impurities from the cloth. The NaOH-treated cotton cloths were then thoroughly washed with cold distilled water. After scouring, the cloth appeared cleaner, softer, and more absorbent, making it suitable for effective dyeing.



Fig 3.3 Scouring of cotton cloth

3.4 Mordanting: Those dyes which do not bind directly but require a mordant, which act as the binding agent between the fiber and the dye [36]. The treated cloth showed increased affinity for the dye, resulting in improved color uptake during the dyeing process.

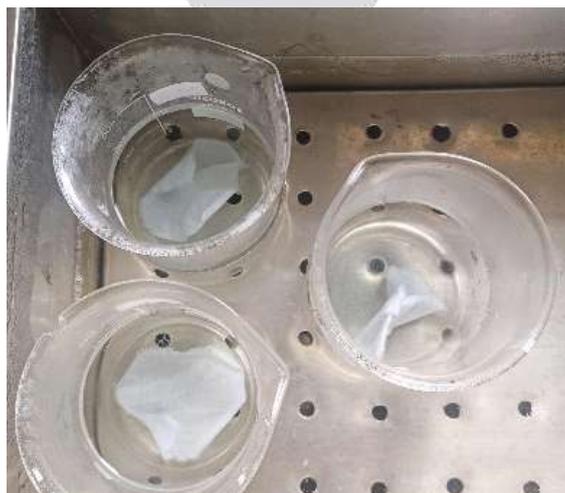


Fig 3.4 Mordanting

3.5 *Dyeing*: The dyed fabrics exhibited distinct shades depending on the type of extract used, indicating successful uptake of natural pigments.



Fig 3.5 (a)



Fig 3.5 (b)

Fig 3.5 (a) and (b) show the cotton cloth being dyed with different dyes extracted by different methods from different weeds.

3.6 *Drying*: After the dyeing process, the cotton fabrics were rinsed thoroughly to remove any unfixed dye and then allowed to air dry at room temperature. The drying process ensured that the color developed fully on the fabric.



Fig 3.6 shows the drying process (1st column weed 3, 2nd column weed 1, 3rd column weed 2)

3.7 Analysis of Colour Pigments from The Extraction

The extracted dye solutions obtained from the three weeds were analysed for their pigment content using a broader range UV-Vis spectrophotometry. UV-Vis spectrophotometric analysis was conducted to identify the absorbance peaks, indicating the presence of various natural pigments. Each extract showed characteristic absorbance in specific wavelength ranges, reflecting their unique pigment composition. These results confirmed the presence of color-bearing compounds suitable for natural dyeing applications.

3.7.1 For the Aqueous extracted samples:

Aqueous extracted Sample	Major Absorbance Range	Likely Compounds
Aqueous1 (<i>Antigonon leptopus</i>)	292–353 nm	Flavonoids, phenolics
Aqueous 2 (<i>Ipomoea cairica</i>)	262–345 nm	Phenolic acids, flavonoids
Aqueous 3 (<i>Lantana camara</i>)	330–360 nm	Flavonoids (fewer visible pigments)

Table 1 shows the comparison of different aqueous extracted samples

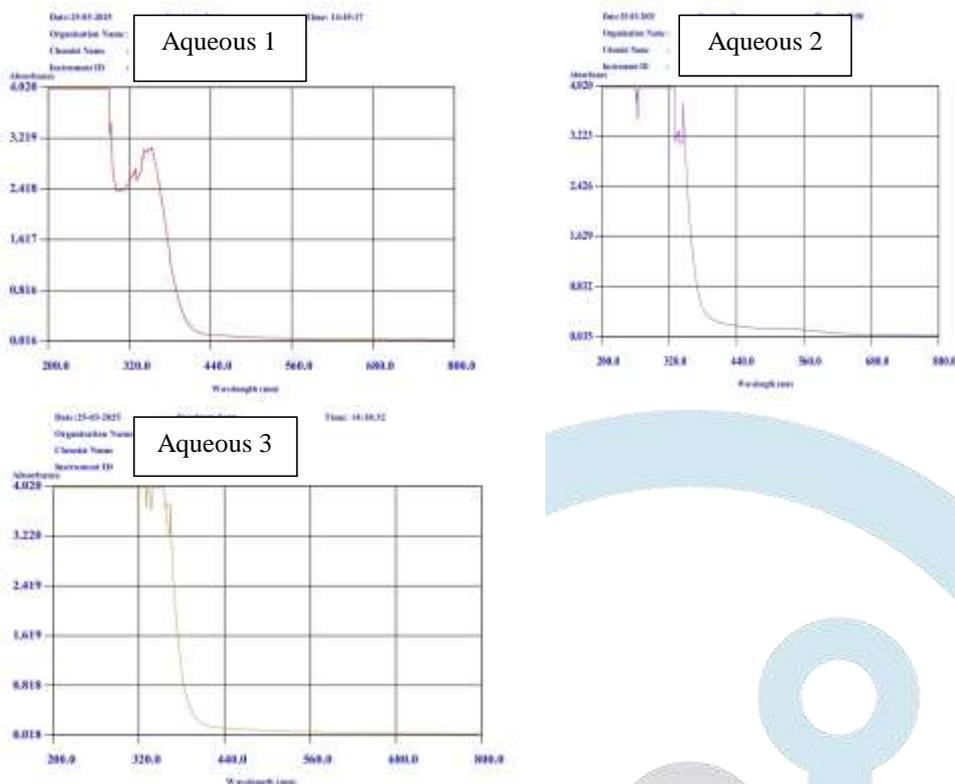


Figure 3.7(a) shows the UV- Vis spectra of all three aqueous extracted samples.

Table 1 and Fig. 3.7(a) reveal that all three aqueous extracts exhibited absorbance primarily in the UV region, indicating the presence of flavonoids and phenolic compounds. Among them, *Antigonon leptopus* showed the broadest absorbance range (292–353 nm), suggesting a richer profile of bioactive pigments compared to the other two species.

3.7.2 For the Chloroform Extracted Samples:

Extract	Peak Absorbance Range	Likely Compounds
Chloroform 1 (<i>A. leptopus</i>)	296–364 nm	Flavonoids, phenolics, alkaloids
Chloroform 2 (<i>I. cairica</i>)	257–342 nm	Phenolics, aromatic acids
Chloroform 3 (<i>L. camara</i>)	342–368 nm	Non-polar flavonoids, carotenoids

Table 2 shows the comparison of different chloroform-extracted samples

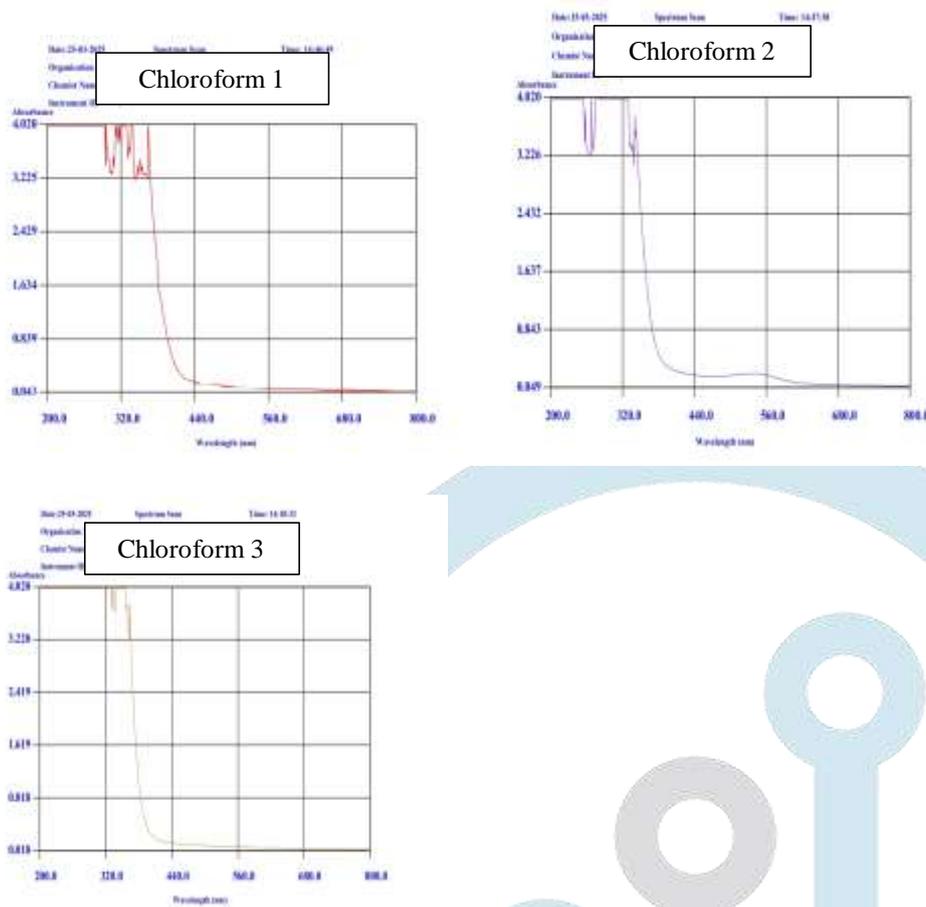


Figure 3.7b shows the UV- Vis spectra of all three chloroform-extracted samples.

Table 2 and Fig. 3.7(b) illustrate that all chloroform extracts exhibited strong absorbance in the UV to near-visible range, indicating efficient extraction of non-polar bioactive compounds.

5.7.3 For the Alkaline Extracted Sample:

Extract	Peak Absorbance Range	Likely Compounds
NaOH 1 – <i>A. leptopus</i>	333–485	Anthocyanins, flavonoids
NaOH 2 – <i>I. cairica</i>	314	Aromatic phenolics
NaOH 3 – <i>L. camara</i>	334–364	Flavonoids, phenolics

Table 3 shows the comparison of different alkaline extracted samples

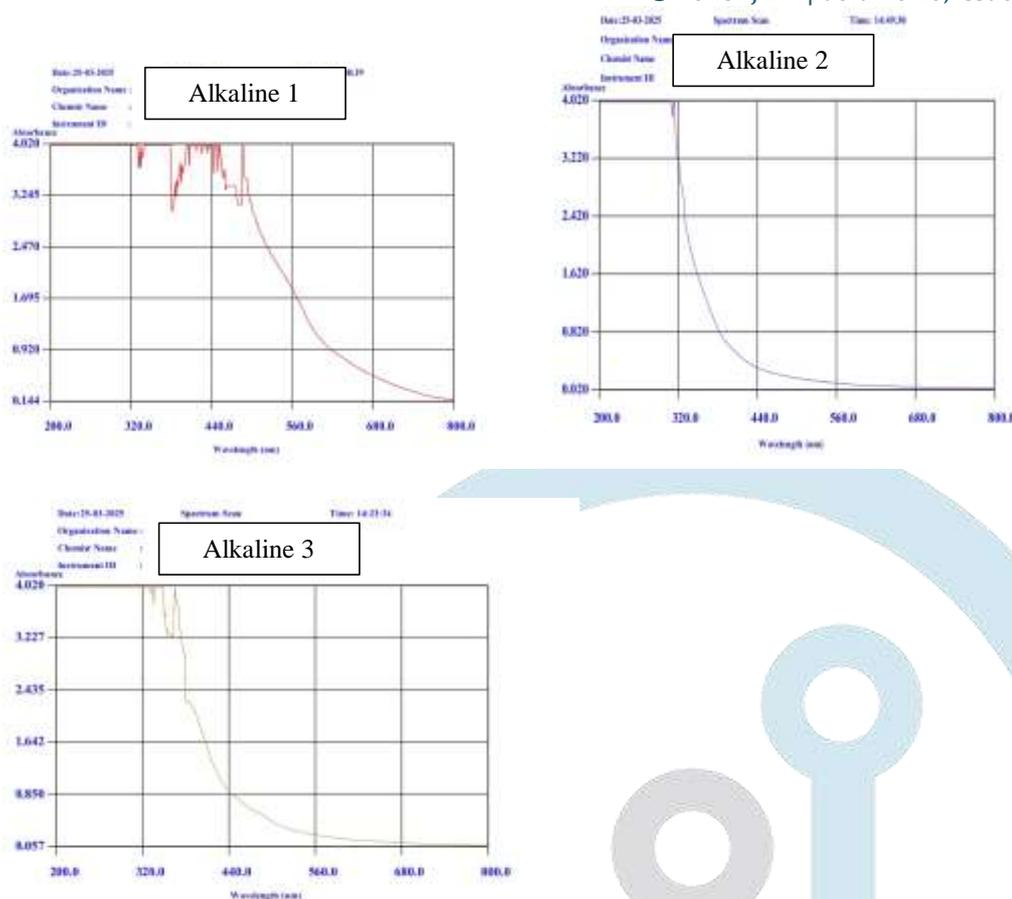


Figure 3.7(c) shows the UV- Vis spectra of all three Alkaline extracted samples.

Table 3 and Fig. 3.7(c) indicate that alkaline extraction effectively enhanced pigment solubility, with all samples showing strong absorbance.

4. DISCUSSION

Fresh flower petals of three different weed species- *Antigonon leptopus*, *Ipomoea cairica*, and *Lantana camara* (Fig. 3.1(a), (b) and (c)) were collected from local areas for pigment extraction. These species were selected based on their abundance in the local environment and the presence of vibrant flower coloration, which often signals high pigment content [39]. Utilizing these readily available and underexplored plants aligns with sustainable practices by minimizing environmental impact and resource use. The colorful petals of these species highlight their potential as sources of natural dyes, offering an eco-friendly alternative to synthetic colorants.

To extract the pigments effectively, three different solvent systems were employed: aqueous, alkaline, and chloroform-based methods (Fig. 3.2(a), (b), and (c)). Aqueous extraction, which involves the use of distilled water, is both simple and environmentally safe and is particularly effective in extracting water-soluble compounds like flavonoids and glycosides [37]. The alkaline extraction, performed with 1% NaOH, enhances the release of pigments such as anthocyanins by breaking down cellular structures and stabilizing these compounds in their anionic forms [40]. Chloroform, a non-polar solvent, targets less polar pigment molecules such as carotenoids and certain flavonoids, offering a broader pigment profile through solubility-based extraction. The variety in extraction methods ensured a more comprehensive recovery of bioactive colorants, with noticeable differences in UV-Vis spectra and dyeing performance, demonstrating how solvent polarity influences pigment extraction efficiency.

Scouring of the cotton fabric was a crucial preparatory step, aimed at removing impurities like starch, waxes, and oils that could interfere with uniform dye uptake (Fig. 3.3). The NaOH treatment facilitated the opening of fiber structures, enhancing the fabric's absorbency and enabling better penetration of dye molecules [35]. Post-scouring, the fabric appeared visibly cleaner and softer, indicating improved readiness for dyeing and contributing to better color uniformity and intensity in the final product.

Mordanting, particularly with ferrous sulfate (FeSO_4), played a vital role in increasing the binding efficiency between the dye and the cotton fiber (Fig. 3.4). As supported by Kumar et al. (2021), some dyes require a mordant to form a stable coordination complex with the fiber, thereby improving color uptake and fastness properties [36]. The mordanted fabrics showed enhanced shade depth and more consistent dyeing results, underscoring the mordant's role as a chemical bridge in the dye-fiber interaction. This step also allowed for the development of unique shades and improved durability of the dye on fabric, confirming its importance in natural dyeing protocols.

The dyeing process produced visually distinct shades on cotton fabrics, correlating with the type of extract used (Fig. 3.5). This color variation is attributed to the presence of different types and concentrations of chromophores in each extract. It also reflects the influence of solvent systems and the chemical nature of the extracted pigments on the interaction with cotton fibers. The successful uptake of color confirms the compatibility of these natural dyes with cotton, supporting their application in sustainable textile processing.

Following dyeing, fabrics were rinsed thoroughly to remove any loosely bound dye particles, an essential step for improving color fastness and preventing post-dyeing staining. Air drying at room temperature was chosen to avoid thermal degradation of the natural

pigments and to ensure proper fixation of color on the fiber. This gentle drying method allowed for the accurate observation of the final color tone and uniformity, which are key indicators of dyeing success (Fig. 3.6).

A preliminary UV-Vis spectral analysis of the three weed petal extracts revealed significant variations in absorbance depending on the extraction method. The aqueous extracts generally showed moderate absorption in the UV range (Fig. 3.7 (a)). Notably, *Antigonon leptopus* exhibited a broader absorption range extending into the near-visible spectrum, indicating the presence of phenolic compounds and flavonoids [38]. *Ipomoea cairica* showed strong absorbance mainly in the lower UV range, suggesting a predominance of simple phenolic structures, whereas *Lantana camara* showed a sharp drop in absorbance in the visible region.

The chloroform extracts demonstrated high absorbance in the UV and near-visible regions across all three samples (Fig. 3.7 (b)). Alkaline extracts (Fig. 3.7(c)), especially from *Antigonon leptopus*, showed strong absorbance extending into the visible region (up to 485.6 nm), suggesting the presence of anthocyanins or their alkaline-stable forms. This indicates strong dyeing potential.

Overall, the comparative analysis of extraction methods, dyeing performance, and UV-Vis spectral data underscores the significant potential of weed flower petals as viable sources of natural dyes, with solvent polarity and mordanting proving crucial in maximizing pigment yield, color vibrancy, and functional textile applications.

5. CONCLUSION

This study demonstrates the promising potential of weed flower petals as a sustainable and eco-friendly source of natural dyes. Through systematic extraction techniques, vibrant pigments were successfully derived from various weed species, highlighting their untapped value. The application of these dyes on cotton fabrics, both untreated and mordant-treated, revealed good affinity, producing visually appealing and enduring shades. Furthermore, UV-Vis spectrophotometric analysis provided insight into the pigment composition and stability, affirming the presence of key chromophore compounds responsible for coloration.

Overall, the findings support the viability of repurposing invasive or underutilized floral weeds as alternative dye sources for textile applications. This approach not only contributes to the diversification of natural dyes but also aligns with sustainable practices by reducing dependence on synthetic dyes and promoting waste valorization. Future studies focusing on optimizing dyeing parameters, improving color fastness, and scaling up the extraction process could further enhance the applicability of these natural dyes in the textile industry.

REFERENCES

- [1] Bechtold, T., & Mussak, R. (2009). Handbook of Natural Colourants. John Wiley & Sons.
- [2] Kant, R. (2012). Textile dyeing industry: An environmental hazard. *Natural Science*, 4(1), 22–26.
- [3] Rather, L. J., Azeem, M., & Dar, B. A. (2016). Environmental and health impacts of textile industry waste. *Journal of Environmental Research and Development*, 10(3), 763–769.
- [4] Samanta, A. K., & Konar, A. (2011). Dyeing of textiles with natural dyes. In *Natural Dyes* (pp. 29–56).
- [5] Siva, R. (2007). Status of natural dyes and dye-yielding plants in India. *Current Science*, 92(7), 916–925.
- [6] Yusuf, M., Shabbir, M., & Mohammad, F. (2013). Natural colourants: Historical, processing and sustainable prospects. *Natural Products and Bioprospecting*, 3, 123–135.
- [7] Arora, A., & Kaur, G. (2019). Extraction and application of natural dye from *Portulaca oleracea* L. on cotton fabric. *International Journal of Scientific Research and Reviews*, 8(2), 1234–1243.
- [8] Bechtold, T., & Mussak, R. (2009). Handbook of natural colourants. Wiley-Blackwell.
- [9] Giusti, M. M., & Wrolstad, R. E. (2001). Characterisation and measurement of anthocyanins by UV-Visible spectroscopy. In R. E. Wrolstad (Ed.), *Current protocols in food analytical chemistry* (pp. F1.2.1–F1.2.13). John Wiley & Sons.
- [10] Kaur, P., & Bala, A. (2022). Application of natural dyes extracted from weed flowers on cotton fabric using natural mordants. *Journal of Natural Fibers*, 19(3), 456–468.
- [11] Lee, H. J., Kim, Y., & Choi, Y. (2020). Enhancement of pigment extraction from wild weeds by fermentation-assisted methods. *Journal of Environmental Biology*, 41(5), 1083–1090.
- [12] Patel, S., Mehta, A., & Solanki, J. (2021). Ultrasound-assisted extraction of natural dyes from *Amaranthus spinosus* and its application on cotton fabric. *Textile Research Journal*, 91(10–11), 1222–1230.
- [13] Samanta, A. K., & Konar, A. (2011). Dyeing of textiles with natural dyes. In E. Akpan (Ed.), *Natural dyes* (pp. 29–56).
- [14] Sari, D. K., Nugroho, R. A., & Wulandari, S. (2018). Solvent extraction of natural dyes from *Cichorium intybus* and *Rumex acetosa* for textile applications. *Asian Journal of Chemistry*, 30(8), 1765–1770.
- [15] Akhtar, S., Ali, A., & Ali, A. (2020). Spectrophotometric analysis of anthocyanins from *Amaranthus* species and their application on cotton. *International Journal of Scientific Research in Biological Sciences*, 7(2), 45–51.
- [16] Gupta, N., Sharma, S., & Bhardwaj, R. (2021). Extraction and characterization of betalains from *Portulaca* and *Beta vulgaris* for natural dyeing applications. *Natural Product Research*, 35(17), 2893–2901.
- [17] Jadhav, S. B., & Sharma, R. (2018). Extraction of chlorophyll dye from *Trifolium repens* and its dyeing application on cotton. *International Journal of Scientific & Engineering Research*, 9(3), 1224–1228.
- [18] Khan, M. I., Siddiqui, M. Z., & Fatima, N. (2022). HPLC-based analysis of carotenoids from *Cichorium intybus* and their antioxidant potential. *Journal of Applied Research on Medicinal and Aromatic Plants*, 28, 100400.
- [19] Kumar, R., & Rani, R. (2016). Utilization of invasive plant species for extraction of natural dyes: A sustainable approach. *Journal of Environmental Science, Toxicology and Food Technology*, 10(5), 12–18.
- [20] Patel, M., & Sharma, K. (2019). TLC analysis and identification of natural dyes extracted from selected weeds. *Asian Journal of Chemistry*, 31(12), 2715–2720.
- [21] Rathinamoorthy, R., & Sumathi, D. (2014). Eco-coloration of cotton with *Lantana camara* floral dye. *The Journal of The Textile Institute*, 105(3), 276–284.
- [22] Sandhya, S., Rani, R., & Reddy, G. (2017). Extraction of anthocyanins from *Amaranthus* and *Bidens pilosa* and their potential applications. *Journal of Natural Products and Plant Resources*, 7(4), 23–29.
- [23] Zhang, L., Yang, X., & Wang, Y. (2019). Extraction, identification, and antioxidant properties of carotenoids from *Chenopodium album*. *Food Chemistry*, 272, 609–615.

- [24] Bhatnagar, A., Verma, R., & Soni, R. (2020). Natural dyeing of cotton fabric using *Portulaca oleracea* flower extract: Effects of mordanting on color fastness and hue. *Journal of Natural Fibers*, 17(5), 667–676.
- [25] Gupta, N., & Mehta, R. (2019). Economical extraction of natural dyes: A review on techniques and challenges. *International Journal of Scientific & Engineering Research*, 10(3), 100–107.
- [26] Kim, H. J., Lee, J. Y., & Park, S. N. (2020). Application of anthocyanin pigments in cosmetics: Evaluation of skin-protective and anti-inflammatory properties. *Journal of Cosmetic Dermatology*, 19(3), 682–690.
- [27] Kumar, R., & Rani, R. (2016). Utilization of invasive plant species for the extraction of natural dyes: A sustainable approach. *Journal of Environmental Science, Toxicology and Food Technology*, 10(5), 12–18.
- [28] Patel, M., Singh, A., & Sharma, K. (2021). Natural dye stability: Recent advances in mordanting and encapsulation techniques. *Dyes and Pigments*, 184, 108844.
- [29] Rani, S., Sharma, V., & Kaur, M. (2018). Environmental factors influencing pigment extraction from wild plants. *Journal of Plant Research and Environment*, 5(2), 45–51.
- [30] Samanta, A. K., & Agarwal, P. (2009). Application of natural dyes on textiles. *Indian Journal of Fibre & Textile Research*, 34(4), 384–399.
- [31] Sharma, N., & Saxena, S. (2021). Potential of *Portulaca oleracea* pigments as safe natural colourants for food and nutraceuticals. *Food Science and Nutrition*, 9(2), 1044–1051.
- [32] Bydoon, E. A. (2017). Extraction of Natural Dye from Tea Leaves and its Application on Giza 86 Egyptian Cotton Fabric. *International Journal of Advanced Science and Engineering*, 3(4), 455–462.
- [33] Kumar, A., Dixit, U., Singh, K., & Gupta, S. P. (2021). Structure and properties of dyes and pigments. In *Dyes and Pigments* (pp. 1–19).
- [34] Ansaria, S., Shaikha, F., Patela, K., Shaikha, F., Dodiya, D., Yadava, A., Charania, S., Sawant, S., & Kelkar, V. (2022). Extraction of natural dye from different flowers for dyeing cotton fabrics. *Journal of Emerging Technologies and Innovative Research*, 9(7), 1–9.
- [35] Chandran, S., Narayanan, R., & Rajan, M. (2021). Textile pre-treatment and dyeing: A review on natural dyeing techniques. *Journal of Natural Fibers*, 18(4), 567–582.
- [36] Kumar, A., Singh, R., & Kumari, P. (2021). Natural mordants and their role in improving fastness properties of natural dyes on textiles. *Asian Journal of Chemistry*, 33(9), 1963–1968.
- [37] Patel, N., & Vankar, P. S. (2014). Green extraction of natural dyes for textile coloration. *Current Trends in Fashion Technology & Textile Engineering*, 1(3), 1–5.
- [38] Sarkar, A. K., & Bhowmick, B. (2015). Application of natural dyes on cotton textiles. In *Eco-Friendly Textile Dyeing and Finishing* (pp. 67–83).
- [39] Sharma, S., Singh, M., & Gahlot, M. (2020). Assessment of locally available weeds for natural dyeing potential. *International Journal of Scientific Research*, 9(11), 12–15.
- [40] Singh, P., & Jain, R. (2019). Alkaline extraction of plant pigments and their dyeing properties. *Journal of Environmental Chemical Engineering*, 7(2), 103020.
- [41] Vankar, P. S. (2007). *Handbook on natural dyes for industrial applications*. National Institute of Industrial Research.
- [42] Ali, S., & Ali, A. (2021). Sustainable dyeing of textiles using natural pigments from wildflowers. *Textile Research Journal*, 91(7–8), 1120–1132.
- [43] Bhargava, S., & Tiwari, A. (2020). A comprehensive review on the eco-friendly applications of natural dyes in the textile industry. *Dyes and Pigments*, 172, 107763.
- [44] Choudhury, P., & Das, S. (2019). Advances in natural dyeing techniques for textiles: A review. *Journal of Textile and Apparel Technology and Management*, 11(2), 1–15.
- [45] Das, A., & Sharma, P. (2021). Exploring the potential of plant-based natural dyes in sustainable textile dyeing: A review. *Environmental Science and Pollution Research*, 28(9), 11545–11560.
- [46] Gupta, R., & Sharma, A. (2018). Extraction and application of anthocyanins from wildflowers for textile dyeing. *Journal of Applied Textile Science*, 14(4), 92–104.
- [47] Khan, N., & Rauf, A. (2019). Plant-based dyes and their ecological benefits in textile industry: A review. *Environmental Impact Assessment Review*, 77, 107283.
- [48] Kumar, R., & Sharma, S. (2020). Application of natural colorants derived from plants for dyeing textiles. *Sustainable Chemistry and Pharmacy*, 16, 100238.
- [49] Malik, A., & Patel, P. (2021). Effect of mordants on color fastness properties of natural dyeing from wildflowers. *Asian Journal of Textile Engineering*, 11(1), 24–35.
- [50] Singh, R., & Singh, S. (2022). Development of eco-friendly textile dyeing from natural sources: Potential and challenges. *International Journal of Environmental Studies*, 79(3), 365–377.