ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in January 2025

Bio-Waste to Bio Dye: Evaluating the Dyeing Potential of Fruit Peels on Cotton Fabrics

Mr. Rahul V. Bharsat, Department of Chemistry, Bhavan's College, Munshi Nagar, Andheri (West), Mumbai-400058, India.
Dr. Archana Kocharekar, Department of Chemistry, Bhavan's College, Munshi Nagar, Andheri (West), Mumbai-400058, India.
Saima Ansari, Department of Chemistry, Bhavan's College, Munshi Nagar, Andheri (West), Mumbai-400058, India.
Nazmin Ansari, Department of Chemistry, Bhavan's College, Munshi Nagar, Andheri (West), Mumbai-400058, India.

Abstract

With rising environmental concerns and the global shift toward sustainable alternatives, the use of natural dyes - particularly those derived from organic waste has gained renewed attention. This study investigates the dyeing potential of fruit peels from orange (Citrus sinensis), apple (Malus domestica), and banana (Musa spp.), analyzing their effectiveness as eco-friendly coloring agents for cotton fabric. Using a basic water-based heat extraction process, dyes were prepared from each fruit peel and applied individually as well as in three specific ratios (5:2:2, 2:5:2, and 2:2:5) to study the impact of mixing on color intensity and stability.

The extracted dyes produced soft, earthy tones - ranging from pale yellow and pinkish hues to beige depending on the dominant fruit in each mixture. Fabric samples were evaluated for light and water fastness by exposing them to direct sunlight and distilled water for 120 minutes. While most dyed samples maintained their color under sunlight exposure, significant fading was observed after water immersion, especially in the mixed-dye ratios. This suggests limited bonding between the dye compounds and cotton fibers in the absence of mordants or fixatives.

The study highlights the potential of fruit peels as a biodegradable, non-toxic dye source, offering a small-scale but impactful approach to sustainable textile practices. However, the results also underscore the limitations of such natural dyes in terms of durability. Further research involving mordants, pigment isolation, and fabric variations could help improve long-term color retention and make fruit peel dyes a more viable alternative in eco-conscious product development.

Keywords: Natural dyes, Fruit peels, Sustainable textiles, Orange peel dye, Apple peel dye, Banana peel dye, Eco-friendly dyeing, Dye extraction, Light fastness, Water fastness, Biodegradable colorants, Cotton fabric, Plant-based pigments, Green chemistry

Introduction

In recent years, there has been a growing shift toward the use of sustainable and environmentally friendly alternatives across various industries. One area that has seen renewed interest is the use of natural dyes, particularly those derived from plant-based waste materials. Among these, fruit peels have emerged as a promising source due to their availability, ease of extraction, and the wide range of pigments they contain. [1] This study focuses on the potential of three commonly available fruit peels: orange (Citrus sinensis), apple (Malus domestica), and banana (Musa spp.) as sources of natural dyes, and evaluates their stability under light and water exposure.

The peels were subjected to a simple dye extraction process involving heat and water, which resulted in distinctly colored solutions: orange peel produced a light yellow extract; apple peel yielded a pale brownish solution, while banana peel resulted in a dull yellow to brown extract. Each of these individual dyes displayed unique characteristics in terms of color and intensity, which became more interesting when they were mixed in various proportions. The study examined three different combinations of these dyes - apple: banana: orange in 5:2:2, 2:5:2 and 2:2:5 ratios in order to assess whether mixing influenced the overall dye performance or stability.

What makes this exploration particularly relevant is the growing need for biodegradable alternatives in industries such as textiles, packaging, and art supplies. While synthetic dyes

dominate the market due to their affordability and consistency, they often come at a high environmental cost, involving harmful chemicals and non-renewable sources. [2] In contrast, fruit peels are biodegradable, non-toxic, and naturally rich in coloring compounds such as flavonoids, tannins, and polyphenols, making them a more sustainable option. Moreover, using kitchen waste like fruit peels not only reduces landfill contribution but also aligns with broader circular economy goals. [3]

The study seeks to understand how these natural dyes perform when exposed to light and water - the two most common factors affecting dye longevity. Notably, while the orange peel dye faded when exposed to light, the apple and banana peel dyes remained largely unaffected. However, when submerged in water, the mixed dye solutions (across all three ratios) showed notable fading, suggesting that water solubility or interactions between the combined compounds may play a role in dye degradation.

By exploring both the individual and combined behavior of these natural dyes, this research aims to contribute to the wider discussion on sustainable coloring methods and their practical applicability. It also opens up questions about the chemical composition of each peel and how their interaction in mixed forms might affect their stability. Though small in scale, the study offers insights into how everyday organic waste could hold untapped potential in green chemistry and eco-conscious product development.

Material and Methods

2.1. Materials: Fresh fruit peels from orange (Citrus sinensis), apple (Malus domestica), and banana (Musa spp.) were collected from local markets. Distilled water was used as the solvent for dye extraction. White cotton cloth pieces were used as the substrate for dyeing. Standard laboratory glassware, including beakers and containers, were utilized for sample preparation and storage. A hot plate served as the heat source for extraction. For light exposure, samples were subjected to natural sunlight. Measuring instruments such as weighing scales and graduated cylinders ensured precise measurements.

2.2. Preparation of Dye Extracts and Dyeing of Fabric: Fourteen grams of each fruit peel were weighed and immersed separately in 100 cm^3 of distilled water. The mixtures were heated at approximately 80°C for about 30 minutes to extract natural dyes. After heating, the solutions were filtered through muslin cloth to remove solid residues and cooled to room temperature. White cotton cloth pieces were immersed in the respective dye solutions and soaked for 24 hours at room temperature to ensure thorough dye absorption. Following this, the dyed cloth samples were removed and air-dried under shade prior to testing.

2.3. Preparation of Dye Mixtures: Individual dye extracts from orange, apple, and banana peels were combined in three volumetric ratios: 5:2:2, 2:5:2, and 2:2:5 (apple:banana:orange). Each mixture was homogenized by gentle stirring to achieve uniform color distribution. Dyeing of cotton cloth with these mixtures followed the same procedure as for the individual dyes.

2.4. Exposure to Light and Water: The dyed cotton cloth samples, both individual and mixed, were exposed to natural sunlight for 120 minutes at ambient temperature to assess light fastness. In parallel, identical samples were immersed in distilled water for 120 minutes to evaluate water fastness. Observations on color retention and fading were recorded after each exposure.

Results and Discussions

3.1. Visual Observation of Dyed Fabrics: The fabrics dyed using fruit peels: orange, apple, and banana were evaluated based on the colors they produced and how they reacted to water and sunlight exposure. Each extract was used both individually and in mixed ratios of 5:2:2, 2:5:2, and 2:2:5, reflecting dominance of apple, orange, and banana respectively. The aim was to observe not only the resulting shades but also the fastness of these natural dyes under external conditions.

3.2. Individual Dyes Performance: Each individual fruit peel dye imparted a visible yet soft

ISSN: 2393-8048
International Advance Journal of Engineering, Science and Management (IAJESM)
Multidisciplinary, Multilingual, Indexed, Double Blind, Open Access, Peer-Reviewed, Refereed-International Journal.
SJIF Impact Factor =8.152, January-June 2025, Submitted in January 2025

color to the cotton fabric. Orange peel dye yielded a yellowish tone that was warm and slightly bright upon drying. Banana peel produced a very light, pale yellowish shade almost beige demonstrating its weaker pigmentation. Apple peel dye showed a faint but pleasant pinkish tone, more noticeable than banana and slightly more vibrant than expected from a natural fruit source. After the dyed cloths were exposed to water for 120 minutes, none of the three individual dyes showed any noticeable change or fading. When exposed to sunlight, only the orange-dyed fabric experienced a slight loss of vibrancy, fading subtly, while the apple and banana dyes maintained their appearance with barely any change. This suggests that although the pigments are relatively weak, they remain stable in light over short durations.

3.3. Mixed Dye Ratio Performance: When used in combination, the fruit peel dyes produced similar warm-toned shades, but each ratio brought out a subtle shift based on the dominant ingredient. The apple-dominant mixture (5:2:2) created a light pinkish hue, soft yet warm, clearly influenced by the apple's underlying reddish pigment. The orange-dominant combination (2:5:2) produced a more noticeable yellow tone, slightly brighter than the others, aligning with the vibrant color potential of orange peel. The banana-dominant mix (2:2:5) resulted in a pale yellowish or beige shade, more muted in comparison, highlighting banana's less intense coloring capacity. While each mixture leaned into its dominant fruit's characteristics, all three ratios produced colors within a similar earthy-warm family, making the overall palette look cohesive with only minor tonal differences.

Figure 1: Visual Results of Natural Dyeing

3.4. Exposure to Light: After 120 minutes of direct sunlight exposure, the mixed dye fabrics did not show any major signs of fading or discoloration. The colors stayed largely intact, with their original warmth and tone preserved. Even the slight pink of the apple-dominant mixture and the yellow from the orange-heavy blend held up well under light. This resilience suggests that while the dyes are delicate, they possess a certain photostability when used in combination, which could make them suitable for short-term use in applications where light exposure is common but limited.

3.5. Exposure to Water: Unlike their light stability, the dye mixtures did not fare well in water. Immersion in water for 120 minutes caused significant fading across all three ratio blends. The apple-dominant mixture lost much of its pink tone, turning into a dull beige. The orange-heavy sample saw its yellow hue become patchy and far less vibrant, while the banana-dominant fabric, already pale, became even lighter and nearly colorless in areas. This noticeable fading across all samples points to weak bonding of the natural dye compounds with the cotton fibers, especially in the absence of mordants or fixatives. Without a binding agent, the dyes were easily washed out, highlighting the limitation of these extracts for washable textile use.

Figure 2: Fading and Blotchiness after water immersion

Conclusion

This study explored the potential of natural dyes extracted from orange, apple, and banana peels, both individually and in mixed ratios, as sustainable alternatives for textile dyeing. The extracts imparted distinct yet soft hues—apple peel giving a light pinkish tone, orange peel producing a yellowish tint, and banana peel creating a pale yellow-beige color. When combined in various ratios, the mixtures maintained a similar warm-toned appearance with minor differences based on the dominant fruit.

The dyed fabrics demonstrated good resistance to fading when exposed to sunlight, suggesting a degree of lightfastness that could support decorative or short-term applications. However, their performance under water exposure was significantly weaker, with all samples showing substantial fading. This lack of washfastness is likely due to the absence of mordants, which are typically used to fix natural dyes onto fabric fibers more securely.

Overall, the findings highlight the aesthetic potential and eco-friendliness of fruit peel-based dyes. While visually appealing and environmentally sound, these natural dyes in their raw form currently fall short in durability for regular textile use.

Limitations

One of the key limitations of this study was the absence of mordants or fixatives during the dyeing process. This choice was intentional to assess the raw dyeing strength of the fruit peels, but it directly impacted the colorfastness, especially in water exposure. The fabric used was limited to plain white cotton, which may respond differently to dyes compared to other materials. Additionally, color assessments were based on visual observation rather than spectrophotometric or lab-based analysis, which could have provided more objective and precise results.

The quantity of dye used and the heating conditions were standardized for simplicity, but these factors could be optimized further to enhance pigment extraction and absorption.

Further Scope of Study

Future research can build upon these findings by incorporating natural or synthetic mordants to evaluate how fixatives can improve the bonding and longevity of fruit peel dyes. Testing on a wider variety of fabrics—such as silk, wool, or synthetic blends—may also offer insights into how material type affects dye uptake and retention.

Further chemical analysis of the pigment compounds in each fruit peel can help in isolating the most effective dyeing agents. Exploring other fruit and vegetable waste as potential dye sources can also expand the range of natural colors available. In the long term, this research can contribute toward developing scalable, sustainable dyeing methods for eco-conscious textile production.

References

1. Siva, R. (2007). *Status of natural dyes and dye-yielding plants in India. Current Science*, 92(7), 916–925. Retrieved from https://www.researchgate.net/publication/228365046_Status_of_natural_dyes_and_dye-yielding_plants_in_India
2. Bechtold, T., & Mussak, R. (2009). *Handbook of Natural Colorants.* Wiley. Retrieved from https://onlinelibrary.wiley.com/doi/book/10.1002/9780470744970
3. Saxena, S., & Raja, A. S. M. (2014). Natural dyes: Sources, chemistry, application and sustainability issues. In *Roadmap to Sustainable Textiles and Clothing* (pp. 37–80). Springer. Retrieved from https://www.researchgate.net/publication/289648815_Natural_Dyes_Sources_Chemistry_Application_and_Sustainability_Issues