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Original Article

Extraction of Natural Dyes from Common Kitchen Waste for Sustainable Dyeing Practices

Thwishaa Johar

Manav Rachna International School.

Corresponding Author : thwishaajohar20@gmail.com

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Abstract *- The ecological footprint of artificial dyes in the textile manufacturing industry has resulted in an immediate quest for greener alternatives. This raises questions about whether natural dyes from everyday waste kitchen materials, in combination with natural mordants, are sustainable and efficient alternatives to artificial dyes for dyeing textiles. Natural dyes were extracted from red cabbage, onion skins, and orange peels in this research. These were mordanted onto cotton fibers, employing three mordanting procedures with both synthetic and natural mordants. It was shown in the study that these dyes, being highly concentrated with anthocyanins, flavonoids, and carotenoids, yielded a variety of intense colors. Pre-mordanting was found to consistently produce the strongest and most even coloration among the mo rdanting methods. Therefore, these results validate that kitchen waste can be an effective source of natural dyes, and organic mordants can be as efficient as synthetic ones, providing a sustainable opti on for green textile dyeing.*

Keywords *- Kitchen wastes, Mordanting, Natural dyeing, Natural pigments, Sustainable dyeing.*

1. Introduction

The textile industry is spread globally, generating around 1 trillion dollars, and contributes 7% of the total world exports [1]. Despite its economic significance, this industrial sector ranks among the highest polluters of environmental degradation. A major source of this pollution is the discharge of untreated effluents from synthetic dyes into the water. Chemicals present in synthetic dyes include mercury, lead, chromium, copper, sodium chloride, toluene, and benzene. Exposure to high doses of these substances may result in toxicity and significant adverse effects on human health. Synthetic dyes have been associated with health issues, including cancer, allergies, and skin irritation, affecting both production workers and end-users. Textile dyes function as toxic, mutagenic, and carcinogenic agents, persist as environmental pollutants, and traverse entire food chains. These compounds are soluble organic substances, particularly those categorized as reactive, direct, basic, and acidic, which demonstrate significant water solubility, thereby complicating their removal [1].

Additionally, approximately 1.3 billion tons of global food are wasted annually. Thirty-five percent of food waste originates from supermarkets, shops, and households, with a significant portion remaining suitable for consumption. In a context where hunger persists, approximately one-third of all food produced annually is discarded. Food waste not only intensifies food insecurity but also inflicts significant harm on the environment. Food waste deposited in landfills generates significant quantities of methane. Excessive concentrations of greenhouse gases, including methane, carbon dioxide, and chlorofluorocarbons, absorb infrared radiation, thereby heating the Earth’s atmosphere and contributing to global warming and climate change.

In light of these challenges, a transition to environmentally friendly, biodegradable dye alternatives is essential. Natural dyes are typically extracted from the roots, stems, leaves, flowers, and fruits of diverse plant species. Marigold flowers, beetroot, and indigo are frequently utilized in natural dyeing processes. The bonding chemistry of dyes to fibers is intricate. It encompasses direct bonding, hydrogen bonds, and hydrophobic interactions. Mordants facilitate the binding of dyes to fabric by establishing a chemical bridge between the dye and the fiber, thereby enhancing the dye’s staining capacity and improving its fastness properties. Mordants create insoluble dye compounds within the fiber [2]. Numerous studies have examined pigment extraction from plant materials, including the work by D. Jothi [3] on the extraction of natural dyes from marigolds, which focused on the chemistry, processing, and stability of the marigold pigment, and its applications in textile coloration. The study conducted by Sindra L. Summoogum-Utchanah and Hashita Joyram [4] examined the extraction of natural dyes from commonly accessible plants, specifically beetroot and turmeric. However, the previous studies have predominantly utilized synthetic mordants and have largely focused on the use of edible food waste for natural dye extraction. In contrast, the objective of the present study was to extract natural dyes from kitchen-based wastes such as red cabbage peels, orange peels, and onion skin and check the effectiveness of organic mordants over the inorganic counterparts.

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2. Materials & Methods

2.1. Dye Material

Red cabbage (*Brassica oleracea*), onion skins (*Allium cepa*), and orange peels (*Citrus sinensis*) were collected from local vendors in Faridabad. These materials were selected due to their abundant availability as household and market waste, aligning with principles of sustainable resource utilization. They are also rich in natural pigments-anthocyanins in red cabbage, flavonoids in onion skins, and carotenoids in orange peels, capable of producing a diverse range of hues on textile fibers.

2.2. Mordanting Material

Aluminium Sulfate, which is commonly used as a synthetic mordant because of its ability to form coordination complexes with cellulose and protein-based fibers and colour fastness properties, was used for the above-mentioned dyes. Pomegranate peel extract was used as a natural mordant with the red cabbage and onion skin dye, as it contains tannins which interact with anthocyanins (from red cabbage) and flavonoids (from onion skin) and deepen the color. To prepare the mordant, several pomegranates were peeled and washed. About 100g of dried peels per 1 liter of water were brought to a boil, then simmered for 30 minutes. The extract was then cooled and strained. Lemon Juice was used as a natural mordant with orange peel dye, as it contains citric acid, which repairs the fiber surface, enhancing dye uptake.

2.3. Pigment Extraction from Red Cabbage

100 g of raw red cabbage was sliced into small pieces and placed in a flask with a 1:1 combination of 125 ml ethanol and 125 ml water (v/v). It was then covered with foil and plastic wrap for 1 week. After a week, the red cabbage colour was released into the solution [5].

2.4. Pigment Extraction from Orange Peels

Fresh orange peel waste samples were collected from a local fruit seller. The peels were then sun-dried for a week. About 200 ml of distilled water and 12 g of dried citrus peels were soaked in the distilled water for 48 hours before heating to 60°C for 30 min to yield the dye extract. Next, the dye extract was left for 30 minutes at a room temperature of about 25°C and filtered. The coloured dye solution was immediately used for dyeing since it contains flavonoids, which are sensitive to oxidation and light, and can break down or lose color intensity [6].

2.5. Pigment Extraction from Onion Skin

The onion skins and ethyl alcohol were mixed in a ratio of 1:50 by placing them in boiling water and allowing the skins to simmer for approximately one hour. The following day, the onion skins were strained, and liquid dye extract was collected [7].

2.6. Mordanting and Dyeing

For chemical mordanting, 2 grams of aluminium sulfate was dissolved in 500 ml of distilled water to prepare the mordant solution. Scoured cotton fabric samples were immersed in this solution and heated at 100°C for 30 minutes. Following this treatment, the fabrics were dried without rinsing to preserve the interaction between the mordant and the fiber. For natural mordanting, pomegranate peel extract was used to dye red cabbage and onion skin-based dyes. The extract was prepared using 30% Weight Of Fiber (WOF), and the fabric samples were mordanted overnight in this solution before dyeing. In the case of orange peel dye, lemon juice was employed as a natural acidic mordant. A solution of 60 ml of lemon juice mixed with 600 ml of distilled water was prepared, and the scoured cotton fabrics were treated in this mordant bath at 100°C for 30 minutes, then dried without washing. Three different mordanting techniques were employed: pre-mordanting, simultaneous, and post-mordanting [8]. In the pre-mordanting method, pretreated cotton fabrics were soaked in the respective mordant solution for 30 minutes, then removed, dried, and subsequently dyed using the prepared dye baths. In the simultaneous mordanting method, the scoured cotton samples were placed in a combined dye and mordant solution, allowing both dyeing and mordanting to occur concurrently. In the post-mordanting technique, cotton fabrics were first dyed by immersion in the dye bath alone, and after 10 minutes, the mordant solution was added. After dyeing, all fabric samples were removed from the dye bath, squeezed gently to remove excess dye, and air-dried [9].

3. Results and Discussion

Table 1. Natural dyeing of cloth with different mordanting techniques

Mordanting Method					
Extract	**Control**	**Mordant**	**Pre Mordanting**	**Post Mordanting**	**Simultaneous Mordanting**
Red Cabbage	Pale Violet	Aluminium Sulphate	Magenta Pink	Violet	Violet
Red Cabbage	Pale Violet	Pomegranate Extract	Light Purple	Magenta Pink	Light Purple
Orange Peel	Pale Lemon Yellow	Aluminium Sulphate	Bright Yellow	Yellow	Pale Yellow
Orange Peel	Pale Lemon Yellow	Lemon Juice	Lemon Yellow	Lemon Yellow	Pale Yellow
Onion Skin	Lemon Yellow	Aluminium Sulphate	Bright Fluorescent Yellow	Fluorescent Yellow	Fluorescent Yellow
Onion Skin	Lemon Yellow	Pomegranate Extract	Lavendar	Light Purple	Light Purple

Fig. 1 Colour changes seen after pre-mordanting, simultaneous-mordanting and post-mordanting with pigments isolated from the plant waste material

Key:

S1: Red Cabbage with Aluminium Sulphate - Pre Mordant	**S12:** Orange Peel with Lemon Juice- Post Mordant
S2: Red Cabbage with Aluminium Sulphate - Post Mordant	**S13:** Orange Peel with Lemon Juice- Simultaneous Mordant
S3: Red Cabbage with Aluminium Sulphate - Simultaneous Mordant	**S14:** Orange Peel - Control
S4: Red Cabbage with Pomegranate Extract- Pre Mordant	**S15:** Onion Skin with Aluminium Sulphate - Pre Mordant
S5: Red Cabbage with Pomegranate Extract- Post Mordant	**S16:** Onion Skin with Aluminium Sulphate - Post Mordant
S6: Red Cabbage with Pomegranate Extract- Simultaneous Mordant	**S17:** Onion Skin with Aluminium Sulphate - Simultaneous Mordant
S7: Red cabbage - Control	**S18:** Onion Skin with Pomegranate Extract- Pre-Mordant
S8: Orange Peel with Aluminium Sulphate - Pre Mordant	**S19:** Onion Skin with Pomegranate Extract- Post Mordant
S9: Orange Peel with Aluminium Sulphate - Post Mordant	**S20**: Onion Skin with Pomegranate Extract- Simultaneous Mordant
S10: Orange Peel with Aluminium Sulphate - Simultaneous Mordant	**S21**: Onion Skin- Control
S11: Orange Peel with Lemon Juice- Pre Mordant	

Red Cabbage contains anthocyanins, which are water-soluble flavonoid pigments known for their pH sensitivity. Under acidic conditions, they typically yield red to purplish hues, while under neutral to alkaline conditions, they tend to shift toward green or blue [10,11]. This property made red cabbage extract an excellent indicator of the mordant environment.

Aluminium sulfate, a metal salt mordant with an acidic pH, favored the stabilization of anthocyanins in their flavylium cation form, leading to reddish-purple shades [12]. When used for pre-mordanting, the Al^{3+} ions are pre-bound to the fabric, enhancing dye uptake and fixation due to forming coordination complexes between the metal ions, the anthocyanins, and the fiber functional groups [12]. Simultaneous mordanting yielded similar hues but slightly less uniform dyeing, as the competition between fiber and dye for the metal ions was active during the dyeing process. However, post-mordanting showed some fixation, which was generally less effective, often resulting in paler shades due to incomplete complex formation since the dye had already penetrated the fabric [13]. Pomegranate peel extract, a bio-mordant, is rich in hydrolyzable tannins and exhibits a mildly neutral to slightly alkaline pH. In this environment, anthocyanins tend to convert into quinoidal and anionic forms, producing bluish-green hues [10,11]. Pre-mordanting with pomegranate peel resulted in more intense blue-green shades, suggesting better anchoring of the dye.

Simultaneous mordanting provided acceptable but less consistent coloration. Post-mordanting led to subtle changes in tone but generally lighter shades, as the binding sites on the fabric were already partially occupied or blocked by the dye [13]. Table 1 shows that pre-mordanting proved most effective in enhancing color intensity and uniformity for both mordants, as it resulted in establishing strong mordant-fiber interactions before dye exposure. With orange peel, noticeable colour changes appeared with all three mordanting techniques. Orange peels are rich in flavonoids, including compounds like quercetin and tangeretin, which exhibit pH-dependent color variations. Under acidic conditions, these compounds predominantly exist in their neutral forms. As the pH increases, deprotonation of these flavonoids occurs, leading to reduced binding affinity and noticeable color shifts [14]. As seen in Figure 1, pale yellow to light golden hues were observed with pre-mordanting with Aluminium Sulphate. This is attributed to the initial formation of coordination complexes between aluminium ions and the functional groups on the fabric. It can also be seen that in the post-mordanting method, the fabric showed a slightly duller or muted yellow tone, indicating that fewer dye-metal-fiber complexes were formed due to less efficient binding once the dye was already fixed. For lemon juice, the simultaneous mordanting method, where lemon juice was added directly into the dye bath, resulted in the brightest and most uniform yellow shade. This suggests that the acidic environment aided in both the extraction of colour from orange peel and in facilitating its immediate bonding to the fiber, thus enhancing dye uptake. Citric acid also acted as a mild chelating agent, helping to stabilize the dye molecules and increase their affinity for the fabric. These differences arise due to the pH of the dye bath and the solubility of bioactive compounds in orange peel.

Onion skins are rich in flavonoids, notably quercetin and pelargonidin, which exhibit pH-dependent color variations. Under acidic conditions, these compounds predominantly exist in their flavylium cation form, leading to reddish or purplish hues. As the pH increases to neutral or alkaline levels, deprotonation occurs, resulting in a shift toward green or blue shades. From Figure 1, it can be seen that in the pre-mordanting method, the fabric displayed a rich golden-yellow hue. This is due to the formation of stable dye-mordant-fiber complexes, where aluminium ions bind to active sites on the fabric and later coordinate with the flavonoid compounds during dyeing. However, in the post-mordanting method, a duller, more muted yellow-brown shade was observed since the dye molecules had already bound to the fabric without the mordant, and the subsequent application of aluminium ions led to weaker or less uniform complexation. On using pomegranate extract as a natural mordant, pinkish hues were observed. This suggests a synergistic effect where the pomegranate tannins interacted simultaneously with both the dye molecules and the fiber.

4. Conclusion

This study effectively illustrated how natural dyes derived from everyday kitchen and market waste, such as red cabbage, onion skins, and orange peels, can be used for dyeing fabrics. The presence of pigments like anthocyanins, flavonoids, and carotenoids allowed for a wide variety of vibrant colors on cotton fabric. Among the mordanting techniques tested, pre-mordanting consistently produced the best outcomes, resulting in deeper and more even color distribution. This is likely due to the stronger bond formed between the mordant and the fabric before dyeing. Simultaneous mordanting also yielded good results, though the colors were slightly less uniform. Post-mordanting resulted in the lightest shades, likely because the dye had already attached to the fabric before the mordant could fully interact. A notable limitation of the research conducted was the use of a single fixed concentration for both dye and mordant throughout the process. Testing different concentrations or alternative solvents could have improved dyeing effectiveness. Future studies could expand by exploring other biodegradable waste materials for dye sources, experimenting with various natural mordants, and applying these methods to different fabric types to evaluate pigment durability.

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