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ECO-FRIENDLY NATURAL DYES DERIVED FROM AGRICULTURAL BY-PRODUCTS FOR SUSTAINABLE TEXTILES

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ABSTRACT:
A move towards sustainable alternatives is required due to growing environmental issues raised by synthetic dyes used in the textile industry. Agricultural by-products, which are frequently thrown away as trash, have a lot of promise as natural dyes that are environmentally beneficial. This study investigates the production, use and efficacy of natural colors derived from agricultural waste, including peels of pomegranates, onion skins, banana pseudostems, and turmeric rhizomes. The development of biodegradable dyeing techniques, reducing reliance on chemicals and sustainable waste usage are the main focuses of the study. The results show that dyes generated from agricultural byproducts are excellent for sustainable textile applications. They not only have vivid and durable coloration and also have antibacterial and UV-protective qualities.

The finding showed that these agricultural by-products have good to very good wash and rubbing fastness and may produce a wide range of colors, including yellow, golden, reddish-brown, and earthy. While turmeric and pomegranate dyes demonstrated antibacterial properties and the ability to filter UV rays, the use of natural mordants enhanced shade depth and lightfastness.

The results demonstrate the double benefit of using agricultural waste and sustainable dyeing, which lessens the environmental impact and promotes circular economy principles. In order to create eco-friendly and useful textiles, this study emphasizes the viability of incorporating agro waste valorization into the textile industry.

Keywords: *Natural dyes, Agricultural by-products, sustainable textiles, waste valorization, Eco-friendly dyeing.*

INTRODUCTION:

The dyeing and finishing procedures used in the textile business significantly contribute to environmental deterioration, making it one of the worst pollutants in the world. Over 70% of colorants used globally are synthetic dyes, which have serious negative effects on the environment and human health. Because dyeing procedures are inefficient, an estimated 2,00,000 tons of synthetic dyes are released into water bodies each year (kant,2012). These effluents frequently contain heavy metals, aromatic compounds, and carcinogenic amines, which can pollute water, soil and cause bioaccumulation in aquatic environments (Chung & Cerniglia, 1992). Furthermore, it is very difficult to remove synthetic colors from wastewater since they are not biodegradable and are resistant breakdown (Holkar et al., 2016).

Natural dyes have made a comeback as a sustainable textile coloring option in response to these issues. Natural colors are non-toxic, biodegradable, and safe for the environment because they come from plants, animals, minerals and microorganisms. However, the extensive production of plants that produce dyes is sometimes criticized for taking up a lot of space and water and competing with food crops (Samanta & Agarwal, 2009). In order to get over this restriction, focus has turned to using agricultural waste as possible natural color sources.

Often thrown away as garbage, agricultural residues including fruit peels, vegetable skins, crop stalks, and leaves are full of bioactive substances like polyphenols, flavonoids, tannins, anthocyanins and carotenoids (Shahid & Mohammad, 2013). For instance, banana pseudostems contain polyphenolic chemicals with coloring potential, onion skins are rich in quercetin, turmeric residues are rich in curcumin and pomegranate peel have significant amount of hydrolyzable tannis (Siva, 2007; Yusuf, Shabbir, & Mohammad, 2017). In addition to being an environmentally benign source of color, using these agro waste promotes waste valorization, lessens the impact on the environment, and is consistent with circular economy principles in textiles and agriculture (Yusoff & Arof, 2019).

Meanwhile, textiles frequently acquire extra functional qualities from dyes made from agricultural byproduct, such as antioxidant behavior, antibacterial activity and UV protection which improve the materials' performance in technical and medicinal applications (Gupta & Gulrajani, 2016). Natural dyes are a versatile and ecological substitute in contemporary textile manufacturing because of their extra features, which provide value beyond hue.

With an emphasis on their extraction techniques, dying behavior on natural fabrics, and performance evaluation in terms of colorfastness and functional qualities, the current study attempts to explore the potential of agricultural byproduct as sustainable natural dye sources. This study aims to advance sustainable practices in textiles and agriculture by combining eco friendly dyeing with agricultural waste management.

LITERATURE REVIEW

The use of natural dyes in textile has grown in popularity because of its multipurpose qualities, biodegradability and environmental friendliness. Numerous agricultural byproducts have been investigated as possible natural dye sources; each one offers distinct color hues and other features.

Pomegranate peels (Punica granatum)

One of the most researched agricultural wastes for use in natural dyeing is pomegranate peels. They abundant in hydrolyzable tannins such ellagic acid and punicalagin, which give textiles their yellow to brown hues (Siva, 2007). Pomegranate peel extracts have strong antibacterial qualities against both Gram positive and Gram negative bacteria in addition to their pigment, which increases the usefulness of colored textiles (Adeel et al., 2009). Because of their high tannin content, studies have also shown that they can function as natural mordants, lowering the requirement for artificial coloring agents (Yusuf, Shabbir & Mohammad, 2017).

Onion Skin (Allium cepa)

Frequently thrown away as kitchen scraps, onion skins are a great source of flavonoids, especially quercetin, which gives natural fibers their golden yellow to reddish-brown colors (Samanta & Agarwal, 2009). Studies have demonstrated that when used with alum and iron mordants, onion skin dyes have good wash and rubbing fastness (Shahid & Mohammad, 2013). Moreover, it has been noted that quercetin based dyes improve fabrics' UV protection qualities, making them appropriate for protective and practical apparel (Khatri et al., 2017).

Banana pseudostems (Musa Spp.)

An prolific byproduct of banana farming, banana pseudostems are high in polyphenolic chemicals, cellulose derivatives and natural colors (Reddy & Yang, 2009). Research show that banana pseudostem extracts can provide cotton and silk textile beige to brownish hues, although being less studied than fruit peels. Additionally, they are well known for having antioxidant properties, which aid in the creation of functional fabrics (Chawdhury, 2014). The conversion of banana peudostems into dye supplies promotes sustainable coloring techniques and waste reduction.

Turmeric residues (Curcuma longa)

The rhizomes of turmeric, especially the leftovers following the extraction of curcumin, offer a natural and sustainable supply of yellow pigment. The main bioactive ingredient, curcumin, is widely recognized for combining with natural mordants to produce vivid yellow hues with high wash fastness (Samantha & Agarwal, 2009). The photoprotection of colored textiles is enhanced by turmeric based dyes since they also have UV absorbing qualities (Kamel et al., 2005). Turmeric residues are extremely helpful for medicinal and functional fabrics since curcumin also has antibacterial and anti-inflammatory properties (Yusuf et al., 2017).

Role of Mordants in Natural dyeing

The low affinity and poor fastness characteristics of natural dyes in comparison to synthetic dyes in comparison to synthetic dyes are two of their main drawbacks. Moderants substances that create coordination compounds with dye molecules and fibers are frequently used to get around this. Metallic salts like iron, copper and alum (potassium aluminum sulfate) are examples of traditional mordants that improve color fastness and depth (Shahid & Mohammad, 2013). However there is increasing interest in bio mordants made from natural tannins, myrobalan, pomegranate peel, and other plant based sources due to worries about the toxicity of metallic mordants. These eco mordants enhance dye fixation without adding hazardous chemicals, offering sustainable substitutes (Mishra & Behera, 2016).

MATERIALS AND METHODS

1. Raw material collection

In this work, agriculture by products such as banana pseudostems (Musa app.) onion skins (allium cepa), pomegranate peels (punica granatum), and turmeric residue (curcuma longa) were employed. Local farms, fruit shops, and vegetable seller provided the basic supplies. After propely cleaning all by products with distilled water to get rid of dust and contaminants, they were allowed to dry for seven to ten days in the shade at room

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temperature (25 to 28ºC). A laboratory grinder was used to crush the dried materials into a fine powder, which was then kept in airtight containers until they were needed again.

2. Extraction of Dyes

Agricultural by products contain tannins, flavonoids, anthocyanins, carotenoids and curcuminoids, which are examples of natural hues. Two extraction techniques were used to guarantee the highest possible pigment recovery because these compounds vary in their polarity and solubility.

a) Aqueous Extraction:

Pomegranate peels, onion skins, banana pseudostems and turmeric residues were among the dried and powdered raw materials used for aqueous extraction. Distilled water was added at a material -to-liquor ratio (MLR) of 1:20 to 1:30. For optimal pigment release, the mixture was then heated to 90ºC for one to two hours while being constantly stirred.a clear dye solution was left behind when the solution was boiled, allowed to cool somewhat, and then filtered using whatman filter paper or muslin cloth to get rid of any solid particles. Many natural colorant, including as tannins, anthocyanins, Flavonoids, and glycosides, are polar substances that dissolve easily in hot water, which is the foundation of this technique. In addition to increasing solubility, heat treatment aids in the breakdown of plant material's cell wall, which promotes the release of pigment into the media. To avoid the intervention of salt and minerals that could change the final dye tint, distilled water was used instead of tap water. Because aqueous extraction only needs water and preserves the original makeup of hydrophilic colorants, it is an easy, economical, safe, and environmentally beneficial method. Its drawbacks include its inefficiency with hydrophobic or less polar pigments, such as curcumin, carotenoids, and chlorophylls. Furthermore, heat-sensitive pigments may degrade with extended heating, lowering dye output or changing color.

b) Solvent Extraction:

The powdered plant wastes were steeped in an ethanol-water mixture, typically in the 70:30 ratio, either at room temperature or with gentle heating between 40 and 60ºC, in order to extract the solvent. For several hours, the mixture was continuously stirred to improve the dissolution of the pigment. Following extraction, solid particles were removed from the solution by filtering it, and the solvent was then concentrated using a rotary evaporator or mild heating to create a useable dye solution. This technique work especially well for pigments that are poorly soluble in water, such the curcumin found in banana pseudostems, and some of the flavonoids found in onion skins. The water-ethanol mixture combination offers a balanced polarity that makes it possible to extract pigments that are both hydrophilic and hydrophobic. Because it is food-grade, biodegradable, and less hazardous than other organic solvents, ethanol is favored over them and is therefore consistent with environmentally friendly methods. The capacity to extract a grater variety of colors, create deeper and more concentrated dye solutions, and preserve less polar bioactive chemicals are just a few benefits of solvent extraction. Its drawbacks including the requirement for solvent recovery, somewhat more expenses in comparison to aqueous extraction, and cautious handling because ethanol is flammable.

Aspect	**Aqueous Extraction**	**Solvent extraction**
Solvent used	Distilled water	Ethanol-water mixture(commonly 70:30)
Target Pigments	Polar and water soluble pigments (tannins, anthocyanins, flavonoids, glycosides)	Less polar or hydrophobic pigments (curcumin, carotenoids, certain flavonoids)
Temperature	High temperature (90ºC, 1-2hrs	Mild heating (40-60ºC) or room temperature
Process	Boiling and filtering	Soaking/agitating, filtering, solvent recovery (if needed)
Eco friendliness	Very high (only water used)	High (ethanol is food grade, biodegradable, but needs careful handling)
Advantages	Simple, Safe, low cost, suitable for most hydrophilic dyes	Extracts a wider range of pigments, gives deeper shades, retains hydrophobic compounds
Limitations	Not effective for non polar pigments, risk of thermal	Requires solvent recovery, higher cost,

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	degradation	ethanol is flammable
Best Suited For	Pomegranate peels, onion skins, banana pseudostems (tannins & anthocyanins)	Turmeric residues, carotenoids, flavonoid-rich materials

3. Textile Substrate

Cotton and silk, two natural fibers that are widely used and have a high affinity of natural dyes, were chosen as textile substrates for dyeing studies. Strong and hydrophilic, cotton is cellulosic fiber that is frequently used in clothing and home textiles. Numerous hydroxyl groups in its chemical structure have the ability to interact with dye molecules, especially when mordants are present, improving color fixation and endurance. Conversely, silk is protein-based fiber made of sericin and fibroin, and its structure contains functional groups like amino and carboxyl groups. In contrast to cellulosic fibers, these groups easily interact with natural colorants, producing hues that are frequently richer and brighter. Both cotton and silk fabric were scourged and bleached before dying in order to get rid of natural contaminants including waxes, oils and pectins that may otherwise prevent dye from penetrating and lessen color consistency. In order to ensure that the fabrics offered a clen and responsive surface foe dye absorption, souring increased the fabric’s wettability and bleaching increased its whiteness. Achieving consistent and efficient dyeing outcomes required this preparation.

4. Dyeing Procedure

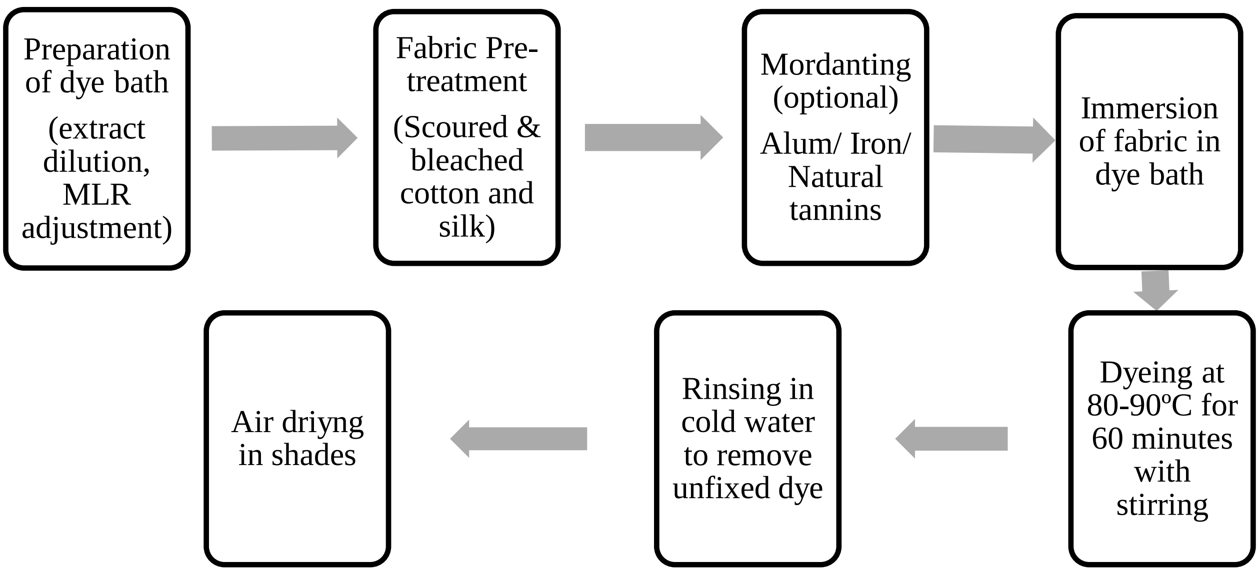

Fig no. 1: Flowchart of dyeing procedure

Cotton and silk fabrics were dyed using the extracted dye solutions in a controlled laboratory setting. The dye baths were made by diluting the aqueous or solvent extracts to the necessary concentration, which ensured a sufficient liquor to goods ratio for uniform dye penetration. Fabric samples were dyed in two different ways: without mordants to examine the fibers’ natural affinity for the dyes and with mordents to assess the impact of mordanting on color strength, fastness, and shade variation. Commonly used mordants included iron (FeSO4), which deepened shades and produced darker hues, alum ($KAl(SO_4)_2 \cdot 12H_2O$), which improved brightness and dye fixation, and natural tannins, which came from sources like gallnuts or myrobalan and functioned as safe for the environment biomordants. This methodical approach ensure consistent dye uptake, reproducible results, and reliable comparison between moedanted and unmordanted samples. The dyeing process was carried out at a temperature of 80 to 90ºC for 60 minutes, with occasional stirring to promote uniform dye absorption. The finished fabrics were then thoroughly rinsed with cold water to remove unfixed dye molecules and then allowed to air dry in shade to prevent photodegradation or shade alteration.

5. Evaluation of dyed fabrics

To ascertain their color strength, fastness characteristics, and functional performance, the colored cotton and silk textiles underwent a methodical evaluation.

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Color strength and shade analysis: Using a spectrophotometrt, color strength and were performed. The depth of shade and amount of dye uptake were measured using the Kubelka-Munk function (K/S value). Stronger coloring and more effective dye absorption by the cloth were indicated by a higher K/S value. The ΔE values, which indicate variations in hue, chroma and brightness between samples were also computed in order to investigate shadow fluctuations. This made it possible to compare color consistency and the impact of mordants on the development of final hue precisely.

Color fastness test: in accordance with worldwide ISO standards, color fastness test were carried out to evaluated the dyed textiles' resilience under several circumstances. Sample were washed with detergent under standard settings to assess washing fastness (ISO 105-C06). The degree of color change and stains on nearby textiles was then graded on scale of 1 to 5, with 5 denoting exceptional fastness. In order to determine the degree of color transfer, the colored materials were rubbed against white in both dry and wet circumstances to test the rubbing fastness (ISO 105-X12). By subjecting the textiles to artificial light for a predetermined amount of time and comparing the degree of fading to blue wool reference scale an industry standard benchmark for light induced degradation light fastness (ISO 105-B02) was ascertained.

Functional Properties: in order to demonstrate the value added potential of natural dyeing, the material were evaluated for their practical qualities in addition to their aesthetic and durability. By placing colored fabric samples on agar plates infected with bacterial strains including Escherichia coli and Staphylococcus aureus, the agar diffusion technique (AATCC 147) was used to test antimicrobial activity. The size and existence of inhibition zones surrounding the fabric samples demonstrated how well the bioactive ingredients in the natural dyes worked to suppress microorganisms. A UV Visspectrophotometer was also used to assess the colored materials' ultraviolet(UV) protection qualities. To find out how well the colored cloth might block damaging UV rays, the Ultraviolet Protection Factor (UPF) was computed.

Result and Discussion

1. Dye Yield and Color Shades

- Pomegranate peels produced bright yellow to brown shades.
- Onion skins yielded golden and reddish brown hues.
- Banana pseudostems provided light beige to brownish tones.
- Turmeric residues showed brilliant yellow coloration.

2. Effect to Mordents

- Alum enhanced brightness and shade depth.
- Iron mordant shifted colors towards darker tones (greenish-brown)
- Natural tannin mordants improved wash fastness while reducing chemical toxicity.

3. Fastness Properties

- Wash fastness: ranged from good to very good (3-4 on grey scale).
- Light fastness: moderate (3-4), but improved with bio mordants.
- Rubbing Fastness: Satisfactory (4-5).

4. Functional Properties

- Antimicrobial test revealed inhibition against E. coli and S. aureus, particularly in turmeric and pomegranate dyed fabrics.
- UV protection values increased significantly, making fabrics suitable for functional clothing.

5. Environmental Impact

- The use of agriculture by-products minimizes solid waste disposal and reduces dependency on synthetic chemicals, promoting a sustainable dyeing industry.

Dye Source	Color Shades	Wash Fastness	Light Fastness	Rubbing Fastness	Functional Properties

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		(1-5)	(1-5)	(1-5)	
Pomegranate Peels	Bright yellow to brown	3-4	3-4	4-5	Antimicrobial activity, UV protection
Onion skins	Golden to reddish-brown	3-4	3-4	4-5	Moderate UV protection
Banana Pseudostems	Light beige to brownish	3-4	3-4	4-5	Moderate UV protection
Turmeric residues	Brilliant yellow	3-4	3-4 (improved with bio-mordants)	4-5	Strong antimicrobial activity, high UV protection

Table no. 2: Comparison between different dye sources of different properties

CONCLUSION

According to the study, pomegranate peels, onion skins, banana pseudostems and turmeric residues are examples of agricultural by-products that may be used as environmentally safe and sustainable sources of natural colors. These waste elements give textiles useful qualities in addition to producing eye-catching color hues that range from deep brown to brilliant yellow. Shade variation, color depth, and fastness characteristics were discovered to be greatly impacted by the usage of mordants, namely alum, iron, and natural tannins. Wash and rubbing fastness were generally excellent (3-5), but light fastness performed moderately well and got better when bio-mordants were used. Apart from their color, colored textiles demonstrated antibacterial properties and improved UV defense, particularly when infused with pomegranate and turmeric extracts. This makes them appropriate for both protective and utilitarian apparel uses. Crucially, this strategy lessens the need for artificial dyes, decreases pollution in the environment, and encourages the value-adding of agricultural waste, all of which help to create a more sustainable textile sector.

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