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Development of a Sustainable Dyeing Process for Cotton fabric Utilizing Natural Dyes from *Punica granatum* L. and *Curcuma Longa*

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Abstract

Pomegranate fruit grains and turmeric have naturally dyeing properties, making them nontoxic, non-allergic, and biodegradable alternatives to synthetic dyes for coloring various textiles, including cotton. This study used pomegranate and turmeric extracts to dye bleached cotton fabric using various mordants, including pre-, post-, and simultaneous mordanting techniques. The natural dyes in these extracts contains alkaloids, tannins, anthocyanins, glycosides, and curcumin, impart different colours to the fabrics. The light sensitivity of these dyes and also role of pH of the dyeing were also explored. The wide ranges of colors were obtained by varying the concentration, ratio, and pH of the extracts, as well as the choice of mordant used. Pomegranate and turmeric extracts demonstrates the potential results as sustainable dyeing and environmentally friendly dyes for cotton fabric.

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Introduction

Natural colors offer vibrant dyes for cotton fabrics. These colors were obtained from minerals, plant parts, trees, and even soil, making them a sustainable and safe choice for various applications. Historically, natural colors have been used for centuries to color food, cosmetics, clothes, furniture, and artwork. From ancient remedies and dyes for cotton fabrics to modern food coloring and ayurvedic medicines, the versatility of natural colors is undeniable.[1,2] Natural color dyes are often obtained from herbs, tree parts, and vegetables. Plants like greenish wattle bark, cocks comb flowers, ripe mango, tea leaves, pomegranate rinds all yield vibrant colors

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when extracted. Even curcumin, commonly found in turmeric, can be used as a natural dye. For added vibrancy and shine, natural dyes can be used with mordents, such as the peel of *Allium cepa* extract, which enhances the color's depth and stability.[3] With their rich history and sustainable nature, natural colors continue to be a popular choice for artists, designers, and those seeking eco-friendly alternatives. Their vibrant hues and diverse applications make them a valuable resource for a variety of disciplines, offering a colorful and harmonious way to connect with the natural world. Natural dyes offer a promising alternative to traditional dyes, particularly for environmentally conscious consumers and producers. Studies have demonstrated that natural dyes, like those derived from *Allium cepa* and metal mordants, can achieve excellent results on cotton fabrics.[4]

Natural dyes like neem extract have been successfully used for cotton dyeing.[5] Pomegranate, a member of the *Punicacea* family, it is 5-10 meter tall and thrives in temperate regions worldwide.[6,7] Its natural pigments, including flavonoids, minerals, and anthocyanins, contribute to its vibrant color and antioxidant properties.[8,9] Anthocyanins, like delfinidin-3,5- diglucoside and cyanin-3,5 diglucoside, play a key role in the color spectrum produced by pomegranate dyes. These natural dyes exhibit good dyeing properties and have the added benefit of being antioxidants. Another promising natural dye is turmeric, an herb belonging to the Zingiberaceae family. Its rhizomes contain curcumin, a compound responsible for its distinctive yellow color. This natural pigment offers the potential for vibrant and colorfast dyeing on cotton fabrics.The utilization of natural dyes like *Allium cepa*, neem extract, pomegranate, and turmeric presents an exciting opportunity for sustainable and eco-friendly textile production. Their potential for achieving excellent results on cotton and other fabrics, coupled with their inherent antioxidant properties, highlights the value of natural dyes in creating beautiful and environmentally responsible textiles.Maharashtra has gross cultivator of cotton crops in the country. Textile industries produce cotton fabric a lot. Cotton is commonly grown as natural fiber. It is hygroscopic, has comfortable heat conductivity and known as cellulose. Now, cotton cloths have no harm to the skin than a variety of synthetic cloths dyeing with synthetic dyes. Such fabrics are harmful, irritant, allergic and carcinogenic as well. It has been found that ten lakh tons of synthetic dyes were used per annum.[10] It produces waste and cause pollution problem. Cotton cloths are not harmful and are healthy, and comfortable for body wearing and various purposes.

Natural dyes are being sustainable,[11,12] biodegradable, compatibility,non-polluting, non-carcinogenic, easily available and ecofriendly in nature[13,14,15] and pollution-free dyeing process.[16] Natural dyes may act as antimicrobial and antioxidant properties.[17] These do not cause any pollution.[18] A cobalt nitrate, Copper sulphate, ferrous sulphate, nickel chloride, and Potassium dichromate was used as mordents for dyeing,[19] and metal salt are used as a mordant and with dyestuff fixes on the fiber. Due to greater affinity, the Mordant had bonded with specific dyes and fixed on fabric.[20,21] Different metal ions as mordant acts as electron acceptor form donors to form coordinate bonds between them. Mortants are light-sensitive.[22] However, natural dyes and the metallic Mordant for dyeing often puts a doubt about eco-friendliness.[23-27] An effluent produced after dyeing may lead to pollution problem. It should be solved by proper treatment of the effluent.Present innovation enables the use coloring natural extracts for dyeing cotton fabrics.

Material and Methods

Analytical reagent (A.R.) grade chemicals, including $CuSO_4$ (Copper sulfate), $NiCl_2$ (Nickel chloride), $FeSO_4$ (Ferrous sulfate), and $K_2Cr_2O_7$(Potassium dichromate), were used directly as mordants.

Pure 100% cotton fabric (plant origin) was purchased from a local market. Before dye application, the fabric was bleached for optimal results.Fresh pomegranate fruits and *curcuma longa* (turmeric) rhizomes were sourced from the Lasalgaon region in Maharashtra, India, for natural dye extraction. Selected pomegranate fruit grains were utilized as the *Punica granatum* (pomegranate) source for traditional dye extraction.

For mordanting the cotton fabric, chemical reagents such as nickel chloride ($NiCl_2$), copper sulfate ($CuSO_4$), potassium dichromate ($K_2Cr_2O_7$), and ferrous sulfate ($FeSO_4$) salts were employed. The

shade of the fabrics intensity was controlled by varying duration of cotton fabric immersion in a dye bath. Lighter shades were achieved by keeping the fabric in the bath for a shorter period, while deeper shades were obtained by leaving the fabric overnight. The open bath exhaust process was chosen as the preferred dyeing technique in this study. This method involves immersing the fabric directly in a dye bath and allows the dye to gradually exhaust onto fibers.

Dye Extraction and Fabric Preparation

For pomegranate dye extraction, 200 grams of Punica granatum fruit grains were collected and juiced with small amount of pure water. The juice solution was clarify and made it to concentrate. Turmeric powder was prepared by grinding dried *Curcuma Longa* rhizomes in a powdered form. To extract the dye, it was submerged in deionized water to specific temperature for one hour. The resulting extract, with a clear yellowish color, was then collected.Both extracts were thoroughly mixed to create the final dye mixture used for cotton dyeing.[28] Prior to dyeing, the cotton fabric underwent a scouring process to remove impurities and enhance dye uptake. This was achieved by bleaching the fabric with a solution of 0.5 g/liter sodium carbonate and at a 50 – 60°C temperature for one hour. The scoured cotton was then dried naturally, ensuring it was clean and ready topass for dyeing process.[29]

Experimental Techniques

This research employed three different mordanting techniques for dyeing cotton fabric and to investigate their fastness.

Pre-Mordanting

Cotton samples were immersed in individual mordant solutions ($CuSO_4$, NiCl2, $FeSO_4$, and $K_2Cr_2O_7$) at (M:L) ratio of 1:30 for two hours. The mordant bath temperature was maintained between 60°C and 85°C.After pre-mordanting, the cotton was dyed using extracted dye mixture at a same temperature at certain time.The dyed cotton fabric washed thoroughly and allowed to dry naturally in the air.

Simultaneous Mordanting

The fabric of cotton was dyed with the extracted dye mixture at 60 – 90°C for two hours.Simultaneously, the chosen mordant and dye bath, with maintaining M:L ratio of 1:30.After simultaneous mordanting and dyeing cotton then naturally air dried.

Post-Mordanting

The selected fabric was bleached and dyed with the extracted dye mixture at 60 – 85°C for specific time. After dyeing, the fabric squeezed to remove excess dye solution.Subsequently, the dyed fabric was treated with a selected mordant solution with M:L ratio of 1:30.The post-mordanted fabric was washed and dried naturally in the air.Each mordanting technique was applied using different mordant chemicals ($CuSO_4$, $NiCl_2$, $FeSO_4$, and $K_2Cr_2O_7$) to assess their color fastness to individual effects on fabrics.[30]

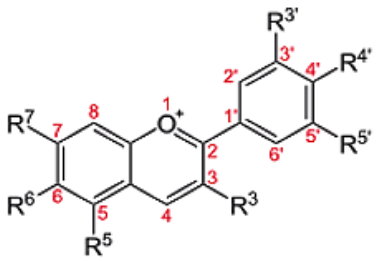


Fig. 1: Basic structure of Anthocyanin

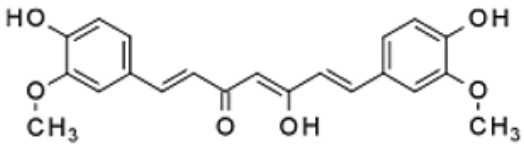


Fig. 2: Structure of Curcumin

Process: Flowchart

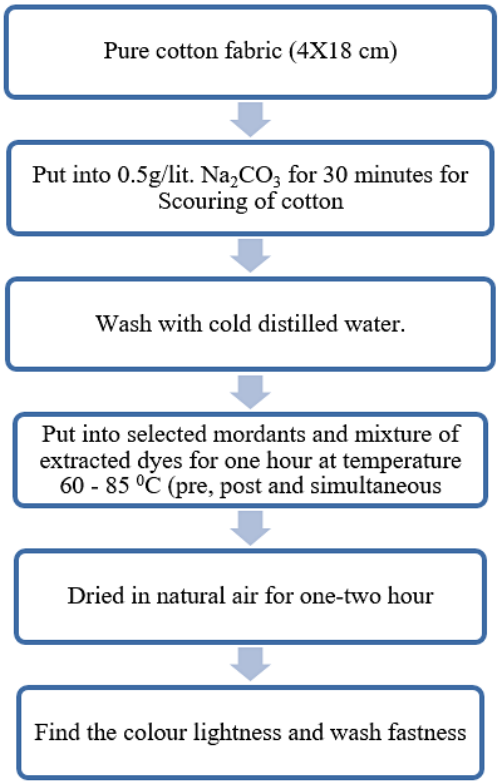


Table 1: Natural extract with different mordants

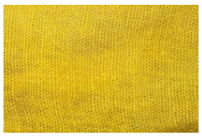
Name of plant present	Parts used	Nature of extract	Mordant used	Pigments
PG + CL	Fruit+ Rhizome	Acidic	$CuSO_4$ K_2Cr2O_7 $FeSO_4$ $NiCl_2$	Anthocyanin + Curcuminoid

Punicagranatum* L- PG;Curcuma longa*-CL

Table 2: Color sheds (Digital Synopsis)

Mordant used	Pre - mordanting shades	Post-mordanting shades	Simultaneous-mordanting shades
$CuSO_4$	Denim-Blue	Olive-Green	Army-Green
$K_2Cr_2O_7$	Flaxen-Yellow	Coffee-Brown	Peanut-Brown
$FeSO_4$	Sangria-Red brown	Mink-Gray	Iron-Gray
$NiCl_2$	Olive-Green	Olive-Green	Mulberry-Violet

Table 3: Dyed sample by using natural extract of pomegranate and turmeric separately

	
Sample without mordanting PG	Sample without mordanting CL

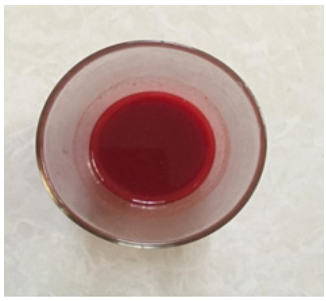


Fig. 3: Mixture of DE

Table 4 a): Dyed sample by using extract mixture and CuSO4 as a mordant

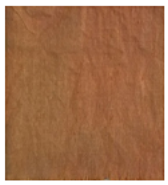
			
Sample without mordanting	Pre-mordanting	Post-mordanting	Simultaneous-mordanting

Table 4 b): Dyed samples by using natural extract mixture and K2Cr2O7 as a mordant

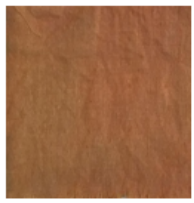
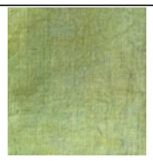
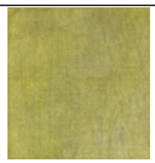
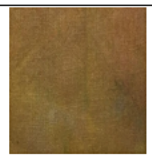
			
Sample without mordanting	Pre-mordanting	Post-mordanting	Simultaneous-mordanting

Table 4. d) Dyed sample by using natural extract mixture and NiSO4 as a mordant

			
Sample without mordanting	Pre-mordanting	Post-mordanting	Simultaneous-mordanting

Result and Discussion

Natural dyes were extracted from *Punica granatum* L. fruit and the rhizome of *Curcuma longa* that produces color; it is due to Curcumin, the structure represented in Figure 2. Both dye extracts (DE) are mixed (Figure 3) the cotton fabric dyed with kind of mordents, as shown in Table 1. Colour strength depends upon the metal salts used. It also shows good fastness properties.The mordant method greatly influences cotton's natural dyeing ability with turmeric extract and *Punica granatum* L. Turmeric is known to have antioxidant and antimicrobial properties.[31,32] The anthocyanin pigment, Delfinidin-3-glucoside, 19% tannin, is majorly present in pomegranate juice; the basic structure is shown in Figure 1. The prepared dyes have a variety of shades such as yellowish, blue, greenish, grey-brown, reddish-brownish, and violet colors used to dye cotton fabric: Table 2, Table 4 (a-d).

The dye mixture showed good bonding with cotton fabric—yellow and green color dye found in pigments present in fruit and rhizome. The strength of color depends upon using Mordant; these metal sources play a vital role in forming a coordinated bond with dye, mordent, and fibers. Cotton fiber is a natural agricultural product highly advantageous to textile industries. It is readily available, comfortable, and has hygroscopic properties. It is natural cellulose fiber. Cotton swells in cold water and, after drying shrinks. The natural dye contains aromatic hydroxyl (-OH) and carboxyl (CO) groups. So, cotton fabric is to be treated as cationized, so cation bonding can occur. It increases the ability and capacity of dyeing. This is a simple method of dyeing cotton fabric. Attractive fresh colors were obtained. It is shown in Table 3. The quantity of dye that used also affects the intensity of fabrics.[33] In nature, many species are available as dyes for dying fabrics. Searching for a new species is a new way to complete the required market demand.[34] This is a new horizon for researcher to investigate the plants and their extract for different coloration. Such fabrics are suitable to wear for better health. This dyeing process was straightforward, easy, efficient, and low-cost.

Wash Fastness

The interaction of a dye with a fiber and the dye's penetration into the fiber's interior constitute the dyeing process. The measurement of color fastness and staining analyses were conducted using a conventional test technique.[35,36,37,38] Table 5 shows light fastness of fabrics dyed with natural extracts with different mordants.[39,40]

It associated with washing rubbing, sun exposure, ironing and use of detergents.

Table 5: Light fastness properties of cotton dyeing with natural dye

Mordants	60 ºC	70 ºC	80 ºC
$CuSO_4$	3.5	4	5
$K_2Cr_2O_7$	3	4	3.5
$FeSO_4$	4	5	5
$NiCl_2$	2.5	3	4

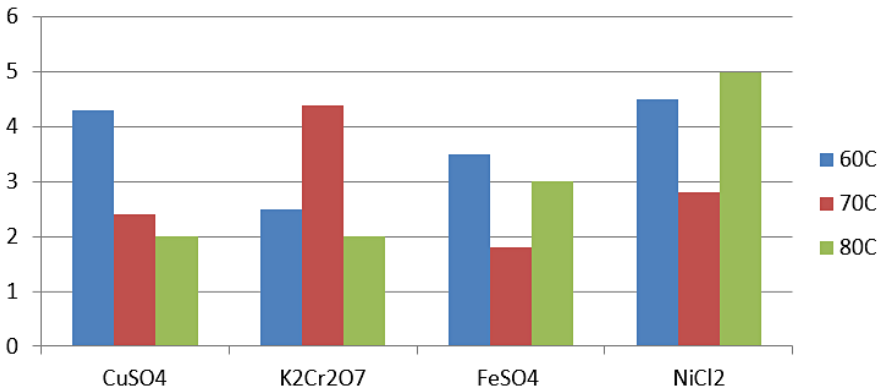


Fig. 3: At different temperatures light fastness of cotton dyed samples

New dyeing technology can help to increase quality and quantity[41]

Conclusion

This research successfully developed a sustainable dyeing process for cotton fabric dyes extracted from pomegranate and turmeric. The study highlights the potential of this dye mixture for textile applications, with key findings demonstrating its versatility and effectiveness. The extracted dye yielded a variety of colour shades with the help of various binders, offering design flexibility. Notably, employing specific mordants significantly improved the colour fastness of the dyed fabric, ensuring durability and resistance to fading. Light fastness was determined as grade 3–4 moderately well. The natural extracts possess inherent antibacterial properties, offering an added benefit for textile use. This innovative approach encourages further research into natural dyes for diverse fabrics, promoting sustainable and environmentally friendly textile production.

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Conflict of Interest

All authors at this moment clarify that, not any conflict of interest.

Data Availability Statement

Data is generated by author undertaken study

Ethics Approval Statement

The study doesn't involve an experiment on humans and animals.

Authors' Contribution

B.B.A.: Conceptualization, design, work on materials, draft writing, editing, and manuscript preparation. S.M.K.: Design of the study and data analysis. A.B.M.: Collection of data and design and V.R.J: Writing and editing of the review.

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