

Sustainable exploration of coffee extracts (*coffea arabica* L.) for dyeing of microwave-treated bio-mordanted cotton fabric

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Abstract

Purpose – This study aims to observe the coloring efficacy of coffee-based natural brown colorant for cotton dyeing under microwave (MW) treatment.

Design/methodology/approach – The colorant extracted in particular (neutral and acidic) media was stimulated by MW treatment up to 6 min. Dyeing variables were optimized and 2–10 g/100 mL of sustainable anchors (mordants) have been used to get colorfast shades.

Findings – It has been found that un-irradiated acidic extract (RE) containing 5% of table salt at 80 °C for 50 min has given high color yield onto MW-irradiated cotton fabric (RC = 2 min). The utilization of 2% of Fe, 10% of tannic acid and 10% of sodium potassium tartrate before bio-coloration, whereas 4% of Fe, 10% of tannic acid and 6% of sodium potassium tartrate after bio-coloration has given good color characteristics. In comparison the application of 6% of pomegranate and turmeric extracts before bio-coloration and 6% of pomegranate and 10% of turmeric extracts after bio-coloration have given good color characteristics. New bio-mordants can be added to get more new colorfast shades.

Research limitations/implications – There is no research limitation for this work. New bio-mordants can be added to get more new colorfast shades.

Practical implications – This work has practical application for artisans, textile industry and handicrafts. It is concluded that colorant from coffee beans can be possible alternative of synthetic brown dyes and inclusion of MW rays for extraction and plant molecules as shade developers can make process more green.

Social implications – Socially, it has good impact on eco-system and global community because the effluent load is not carcinogenic in nature.

Originality/value – The work is original and contains value-added product for textiles and other allied fields.

Keywords Bio-mordanting, Coffee, Cotton, Microwave radiation, Sustainability

Paper type Research paper

Introduction

With the introduction of industrial revolution in the world, the technologists have introduced a lot of products that have made lives, living ways as well as the global environment more charming, attractive and colorful (Haji and Vadood, 2021;

Zheng *et al.*, 2021). Day by day, the rapid rise of public demands have forced researchers to use advanced methods for green products, but such advances have taken a lot of time, energy, labor, cost and new material (Borrás-Enríquez *et al.*, 2021). Of these products, the coloring process of matrix, such as fabric, wool, glass, has gained a lot of fame. Previously, this process was done by natural sources, but with industrial advancement, synthetic colorants have been used (Kovačević *et al.*, 2021; Viera *et al.*, 2019). Till now, thousands of dyes have been formulated and used and are used in almost all walks of

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life (Náthia-Neves *et al.*, 2019; Mahdi *et al.*, 2020). The global village is facing serious global warming issues, which is due to the frequent use of toxic, carcinogenic chemicals (Shabbir *et al.*, 2018). In textile, the colorants need such intermediate and finishing agents that release non-biodegradable toxic effluents (Islam *et al.*, 2018). This toxic burden is not only destroying fertilizer load but also disturbing the ecosystem equilibrium (Samant *et al.*, 2020). The global institutes have seriously noticed that such effluents are non-biodegradable, causing rise in global temperature or taking a lot of money, energy, cost and other resources for the treatment (Islam *et al.*, 2019). Now they have considered that textile and other allied sectors should move toward the nature. The colorants from the nature are not only sustainable, easily disposable and possess no health issues (Zayed *et al.*, 2021). These dyes are extracted from plants, and their effluents can be either recycled or their residues when mix with soil can act as fertilizer (Swami *et al.*, 2014; El-Khatib *et al.*, 2021). These colorants have wide spectrum of colors, but also by tinting these can also provide new shades that can be possible substitutes of synthetic dyes (Barani and Maleki, 2020). Hence, the revival of the art of natural dyes is now the global demand, particularly in the present pandemic situation (Prado *et al.*, 2020).

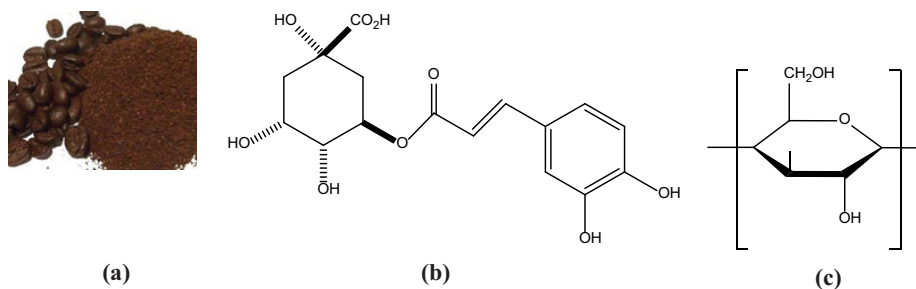
Plant sources share a lot of colors in the field of textile. Colors can be extracted in various media through different parts such as seeds, roots, flowers, barks, leaves and stems (Jabar *et al.*, 2021). Among seeds, coffee beans powder [Figure 1(a)] is the source of the brown natural dye. Coffee belongs to Rubiaceae family (Koh and Hong, 2019). It contains mostly alkaloids, quinolinic acid, nicotinic acid, tannic acid, pyrogallol acid and trigonelline, which impart anti-oxidant properties (Nam and Xiang, 2019). Its oil is also used in medicine as health-care and sunblock products (Herlina and Kurniati, 2020). Coffee extract is useful for prevention of nervous shock, anemia, influenza, common cold, hepatoprotective and lungs diseases (Hao *et al.*, 2019; Jong-Sup *et al.*, 2019). It also acts as a cardio-tonic nuerotonic and possesses excellent anti-inflammatory, anti-allergic anti-bacterial, hypoglycemic, anti-diabetic and anti-cancerous activities (Chiari *et al.*, 2014; Elabid *et al.*, 2021). The main phytochemicals are caffeine, chlorogenic acid, polyphenols, flavonoids, alkaloids, etc., but polyphenol (chlorogenic acid) is main functional moiety [Figure 1(b)] that imparts the brown color onto the matrix (Lee *et al.*, 2017; Seemork *et al.*, 2020). Cotton is the major fabric that has

cellulosic unit where its –OH group is used for binding with the colorant [Figure 1(c)].

Previous studies show that natural dyes when isolated show low yield, give poor fastness ratings and cannot give reproduce same shades (Nathia-Neves *et al.*, 2020). The researchers using classic methods such as soaking, stirring, heating, boiling, maceration, refluxing, etc. (Samant *et al.*, 2020) found that such approaches are not cost, energy and time effective (Ranjha *et al.*, 2021). Currently, contemporary approaches such as microwave (MW), ultraviolet, ultrasonic, gamma and plasma radiations are being used (Fadil *et al.*, 2021). But, MW is the cheap, leveled and uniform and easily available heating source for abstraction of plant pigments (Abdelileh *et al.*, 2021). These rays penetrate into fabric and turn its surface to enhance its substantivity (Arain *et al.*, 2021; Jafari *et al.*, 2019). These rays collapse with plant materials, burst its cell wall and make effective interaction of functional moiety (colorant = chlorogenic acid) with solvent through mass transfer kinetics (Buyukakinci *et al.*, 2021; Handayani *et al.*, 2019). By such rapid and effective response, not only less energy and time are used, but also less solvent is consumed with production of high yield (Majumder *et al.*, 2020). To overcome fastness issue, electrolytes such as salt of Al, Fe, Cu, Cr, etc. are used, but environmental agencies forced that salts of Cu, Cr, Co, Ni, etc. are oncogenic and retain serious fears to the environment (Islam *et al.*, 2018; Rather *et al.*, 2018). Now, as the probable substitute, plant-based molecules have been introduced. These sources hold brilliant biological characteristics but also furnish soothing and sustainable fast shades (Hosen *et al.*, 2021). Such bio sources are now being used since past five years, and the dyed bio-mordanted shades have given well to excellent fastness rating (Hosseinnezhad *et al.*, 2021). This study has been aimed to:

- appraise coffee bean-based chlorogenic acid as brown natural dye MW rays treatment for cotton dyeing;
- analyze physiochemical changes in the functional behavior of cotton fabric through scanning electron (SEM) and spectral images (FTIR);
- to get optimum dyeing conditions using slected irradiation conditions for mordanting;
- use sustainable chemical and bio-anchors at selected conditions to improve the shade quality; and

Figure 1 Coffee beans powder (a) chlorogenic acid (b) cellulosic unit (c)



- to assess shade fastness of selected mordanted fabrics as per SIO standards.

Experimental

Materials

Finely ground powder of coffee beans (*Coffea Arabica L.*) was obtained from the native market. The ground beans powder was sieved up to 20 meshes and stored. Cotton fabric used for dyeing has been pretreated to make it ready for bio-coloration. Plant materials (pomegranate and turmeric) used as bio-mordants were also prepared using already published work of Habib *et al.* (2021).

Extraction and irradiation process

Natural colorant (chlorogenic acid) from coffee beans was isolated by using 4 g of coffee powder at boiling with 100 mL of distilled water (aqueous = neutral medium) for 45 min, keeping coffee powder to aqueous medium ratio (CP: AM) of 1:25 (Adeel *et al.*, 2021b). Extracts and pre-ready cotton fabrics were microwaving irradiated (MW) for 1–6 min a commercially available orient oven of 50 Hz with the power of 700 W. To get good yield in terms of color depth (K/S), MW (RE) and un-MW irradiated extracts (NRE) were applied to dye MW (RC) and un-MW irradiated cotton fabrics (NRC) at 80°C for 50 min.

Dyeing and colorfast shade-making process

After selection of medium for isolation and irradiation level (min) for stimulation of fabric surface, the selection of contact levels were carried out at 50–90°C with an interval of 10°C for 20–60 min with an interval of 10 min. For getting maximum exhaustion of colorant toward fabric, 1–5 g/100 mL of table salt was used. The chemical mordants (2–10 g/100 mL) and the extracts (2–10 g/100 mL) from fresh turmeric rhizomes powder (*Curcuma longa*) and pomegranate peels powder (*Punica granatum*) were also used at given condition to improve coloring properties of cotton dyed with coffee beans extracts. The extract of bio-mordants prepared and sustainable chemical anchors were used by following the already documented methods of Khan *et al.* (2021) and Adeel *et al.* (2022).

Investigation of un-dyed and dyed fabrics

Cotton fabrics before and after irradiation for 2 min were analyzed for any chemical change through FTIR tool (Perkin Elmer, USA) at the Institute for Color Science and Technology, Iran. Similarly, the changes in surface morphology of cotton fabric before and after MW treatment for selected time have been observed through surface electron microscopy (SEM model Tescan; 5 kV at 1,000x). Color characteristics of all dyed fabrics through Spectra flash SF 600 (Data Color, USA) have been assessed. ISO standard methods of light (ISO 105-B02), washing (ISO 105-C03) and rubbing (ISO 105-X12) at the optimum dyed fabric have been used and rated at gray scale.

Results and discussion

The influence of MW rays in extraction of functional biological molecules is gaining fame day by day (Abdelileh *et al.*, 2021; Adeel *et al.*, 2021b). This is because the rays transfer energy

into the solvent molecules, which collapse with plant cell wall to burst. After collapse, the functional molecules are evolved out through solid liquid interaction and upon dyeing give promising yield. This process depends upon nature of colorant, level of MW and solvent used, which gives excellent mass transfer kinetics to give significant results (Arain *et al.*, 2021; Adeel *et al.*, 2022). Same is the finding have been observed in the study, where the coloring efficiency of coffee powder has been explored for cotton coloration. The results given in Figure 2 show that aqueous extract (RE) treated for 1 min has given high color yield (K/S) onto irradiated fabric (RC = 1 min) as compared to un-irradiated extract (NRE) used for dyeing of un-irradiated fabric (NRC). On changing medium, the results given in Figure 3 show that application of un-irradiated extract (NRE) has given excellent color yield (K/S) onto irradiated fabric (RC = 2 min). Here, other factor, which is very important, is the surface tunning of cotton (cellulosic fabric) by microwave rays. For 2 min, treatment of the physical modification of surface has been occurred, which in turn has raised its uptake-ability; However, the chemical nature of cellulosic fibers has not changed, which has been verified by FTIR Figure 4(a)–(c). The broad band in this region is due to the OH-stretching vibrations arising from hydrogen bonding in

Figure 2 Dyeing of cotton fabric with aqueous coffee extract before and after MW radiations

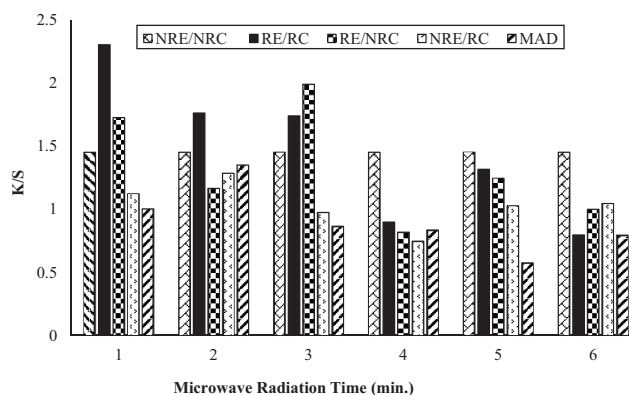


Figure 3 Dyeing of cotton fabric with acidic coffee extract before and after MW radiations

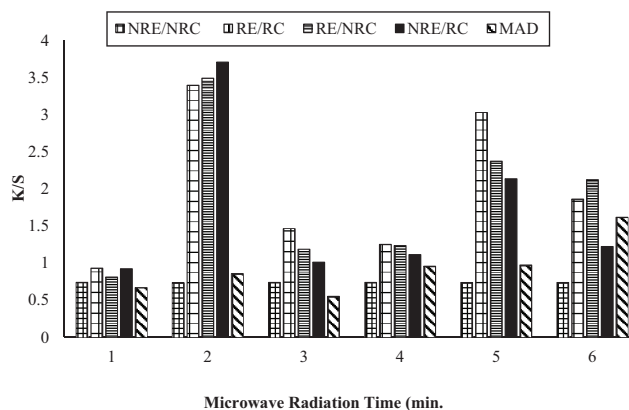
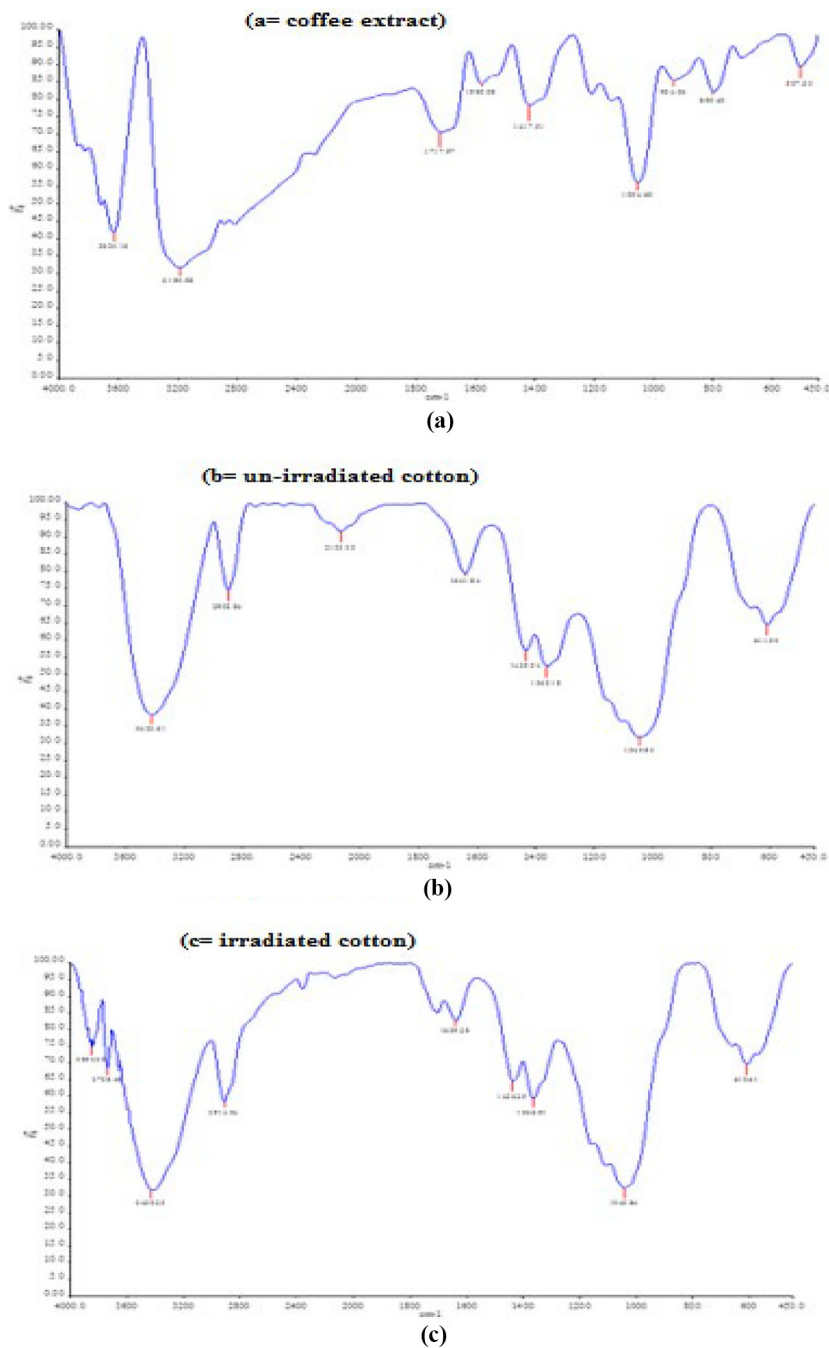


Figure 4 FTIR spectra of coffee extracts (a) un-irradiated (b) and irradiated cotton (c)

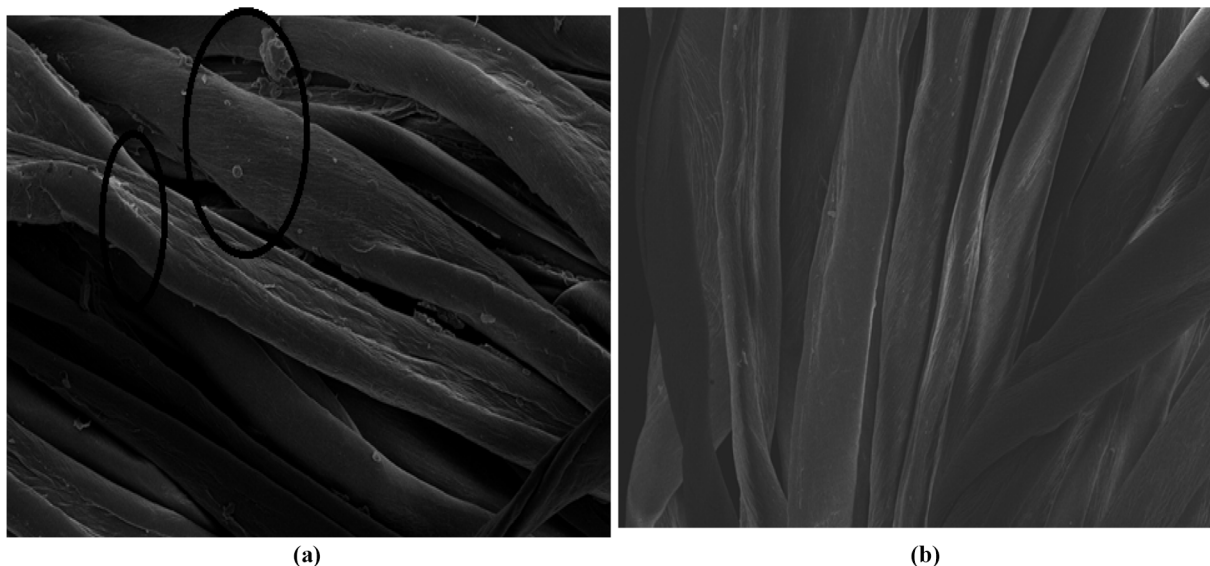


cellulose. One of two main vibrations, at $3,300\text{ cm}^{-1}$, became visible that can be assigned to intra-molecular hydrogen bonding of cellulose. The other main vibration, at $3,200\text{ cm}^{-1}$, was evident in all spectra, which can also be assigned to inter-molecular hydrogen bonding of cellulose. Spectral image of coffee extract, multiple peaks became at $3,634$ and $3,190$, $1,717$ and $1,054\text{ cm}^{-1}$ corresponded to O–H, C–H, C=O and C=C group stretching vibration, respectively. These spectral data confirmed chlorogenic acid extract’s structure

[Figure 4(a)]. Hence, before and after radiation, the characteristics peak for cellulosic unit has not been altered, whereas SEM images displayed in Figure 5(a)–(b) show that these rays have caused modification by scratching the surface, which, in turn, has enhanced the dye uptake-ability.

It can also be seen that on rise of MW rays time, the other phytochemicals caffeine, polyphenols, flavonoids and alkaloids may also get dominant chance to adsorb along with colorant onto fabric, due to which the low tint strength has been

Figure 5 SEM images of MW irradiated (a) un-irradiated cotton fabrics (b)



observed. Hence, it is recommended that extraction should be done in acidic medium, without exposure to MW rays, but fabric should be tuned for 2 min to get high yield. The data presented in Table 1 using aqueous extract show that red shades more toward green on rising MW time, whereas yellow tone is also decreasing with rise of brightness. However, the irradiated fabric dyed with irradiated extract is darker in shade ($L^* = 62.13$) as compared to un-irradiated extract and more reddish yellow in tone ($a^* = 4.68$; $b^* = 17.33$) as compared to un-irradiated extract ($L^* = 67.96$; $a^* = 4.36$; $b^* = 16.58$). On using acidic extract, the shades are brighter than having less-redder but more yellowish tone. However, the irradiated fabric (RC = 2 min) dyed with un-irradiated extract (NRE) is darker in shade ($L^* = 61.87$) and reddish yellow in tone ($a^* = 4.45$; $b^* = 16.58$) as compared to brighter shade of un-irradiated dyed fabric ($L^* = 64.19$) with greenish yellow tone ($a^* = 2.10$; $b^* = 12.20$). Hence, for getting darker shades with reddish yellow tone of high color yield, un-irradiated acidic extract (NRE) should be used to color irradiated fabric (RC = 2 min).

The bio-dyeing of the cellulosic fabric using plant extracts needs contact levels. For low time, contact of irradiated fabric with un-irradiated extracts, less color yield is

observed, whereas for long time contact, the rate of desorption becomes dominant and also tint strength is found. The results given in Figure 6 showed that dyeing of irradiated fabric for 50 min using un-irradiated extract has given promising results. The rise of heating level slowly caused leveled dyeing rate up to optimum level. After optimum level (80°C), the desorption is occurred, and dye bath equilibrium is disturbed. Hence, too much and too low heating the actual equilibrium of dyeing rate are disturbed, and low color strength is found. It is recommended that dyeing of irradiated fabric at 80°C for 50 min should be done using un-irradiated coffee extract.

The color coordinate given in Table 1 shows that mostly fabric dyed is brighter in shade but greenish yellow in tone. The fabric dyed for 50 min is brighter in shade and reddish yellow in tone ($L^* = 82.49$; $a^* = 4.14$; $b^* = 17.97$), whereas fabric dyed at 80°C is also brighter in shade and reddish yellowish hue ($L^* = 84.52$; $a^* = 3.44$; $b^* = 17.97$). Hence, MW irradiation of fabric has reduced the dyeing levels (time and temperature), which shows its time and energy promising nature. Salt when added in the extract, it tries to neutralize the charge of the fabric and tries to interact the colorant with functional site of fabric by interactive forces to give maximum yield (K/S) (Batool et al., 2022). Low amount of salt cannot exhaust the colorant from solution toward fabric, whereas only optimum amount (5 g/100 mL) can give promising exhaustion to give high strength – Figure 6. The color coordinates given in Table 1 shows that irradiated fabric dyed with un-irradiated extract containing 5 g/100 mL of salt has given darker shade ($L^* = 79.30$) with reddish yellow tone ($a^* = 5.38$; $b^* = 20.98$).

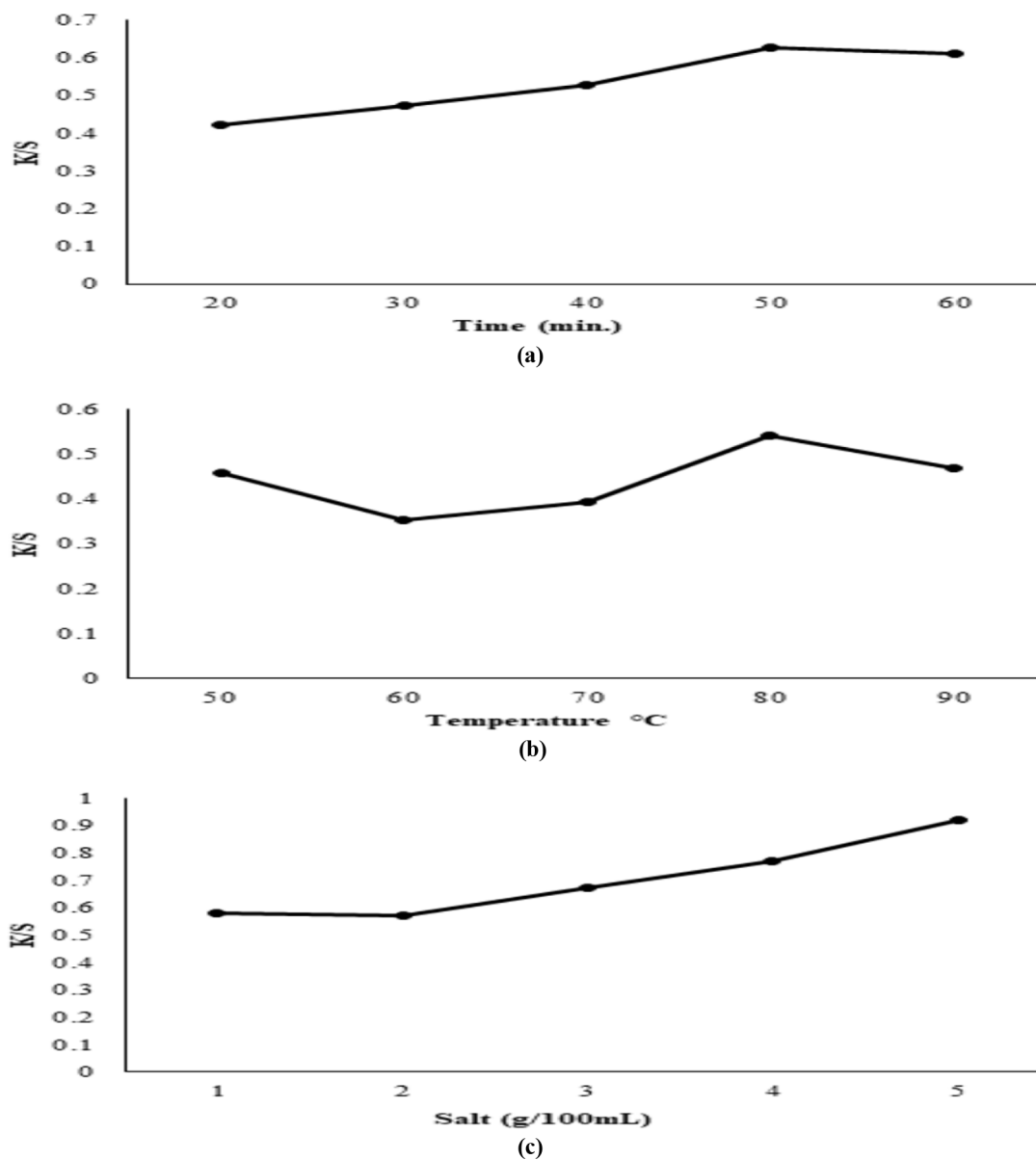
Cotton dyeing with plant dyes always requires fixers to have firm and fast shades. Such fixers are either tannic acid and metal salts or plant-based functional isolates, which helps to add value in natural dyeing of cotton (Habib et al., 2021; Khan et al., 2021). In this study, these chemical fixers have been used for mordanting of irradiated fabric at 60°C for 45 min. The

Table 1 Shade variable of cotton fabric bio-colored at selected conditions

Extraction conditions	L^*	a^*	b^*
Aqueous 1 min RE/RC	62.13	4.68	17.33
Acidic 2 min NRE/RC	61.87	4.45	16.58
Parameters			
Dyeing conditions	L^*	a^*	b^*
Time = 50 min	82.49	4.14	17.97
Temperature = 80°C	84.52	3.44	17.97
Salt = 5 g/100 mL	79.30	5.36	20.98

Notes: RE = irradiated extract; RC = irradiated cotton; NRE = un-irradiated extract; L^* = lighter/darker; a^* = redder/greener; b^* = yellower/bluer

Figure 6 Dyeing of cotton fabric at various dyeing conditions using acidic coffee beans powder extract



results given in Figure 7 reveal that application of 2 g/100 mL of iron salt before dyeing of irradiated fabric with un-irradiated extract has given high color yield. On use of iron salt (4 g/100 mL) after dyeing of irradiated fabric with un-irradiated extract has given high color yield displayed in Figure 8. The shade variables given in Table 2 show that dyed fabric before mordanting with iron salt is reddish yellow in hue with bright shades ($L^* = 75.52$; $a^* = 7.80$; $b^* = 22.28$). As compared to the fabric dyed after mordanting. The use of tannic acid (10 g/100 mL) before and after dyeing of irradiated fabric with irradiated extract has given high yield, where the shade variables shown in Table 2 reveal that shade obtained before pre-mordanting is darker and much reddish yellow in tone ($L^* = 72.89$; $a^* = 9.12$; $b^* = 15.36$). The application of 6 g/100 mL of sod pot tartrate before dyeing and 2 g/100 mL of sod pot tartrate after dyeing has given high color yield, as shown in

Figures 7 and 8. The color coordinates given in Table 2 show that in both cases, the shade is brighter but greenish yellow in hue ($L^* = 87.80$; $a^* = 2.06$; $b^* = 12.97$). On comparative analysis, tannic acid and iron salt have been found good for bio-coloration of cotton with coffee extract. This is because iron forms complex with dye onto fabric via coordinate covalent bond, whereas tannic acid form H-bonding with -OH of colorant and -OH of surface-modified cellulosic fabric to give good color characteristics (Geelani et al., 2017; Rather et al., 2018; Shabbir et al., 2017). The proposed interaction of metal with colorant and fabric has been displayed in Figure 9(a).

Plant-based molecules are nowadays being used for color fastness of fabric dyed with natural dyes as well as for firm and sustainable shades (Rather et al., 2019; Yusuf, et al., 2017). Mostly, herbal-based molecules have been used with -OH group responsible for firm interaction and transfer of biological

Figure 7 Effect of pre-chemical and bio-mordanting on the color strength of cotton with acidic coffee extract

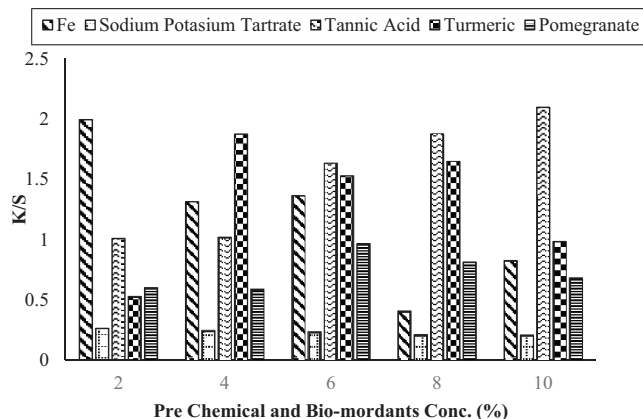
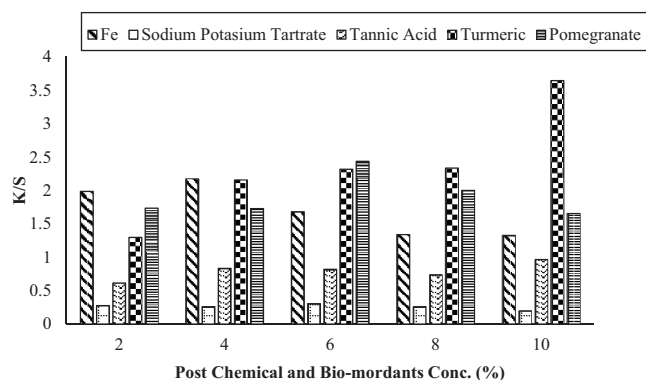


Figure 8 Effect of post-chemical and bio-mordanting on the color strength of cotton with acidic coffee extract



characteristics onto fabric (Adeel et al., 2021c; Bukhari et al., 2017). In this study, extract of turmeric having curcumin and tannin by pomegranate extracts have been used before and after dyeing of cotton with coffee extract. The results given in Figures 7 and 8 show that 4 g/100 mL of turmeric extract before and 10 g/100 mL of turmeric extract after dyeing of irradiated cotton have given high yield (K/S). On use of 6 g/100 mL of pomegranate extract before and after dyeing of irradiated cotton with coffee extract has given good yield. The overall turmeric extract has given high yield. The proposed interaction of metal with colorant and fabric has been displayed in Figure 9(b). The shade variables given in Table 2 show that fabric pre-mordanted with 4% followed by dyeing in brighter in shade and reddish yellow in hue ($L^* = 72.41$; $a^* = 12.98$; $b^* = 45.98$), whereas post-mordanted with 10% turmeric extract is less-brighter and reddish yellow in hue ($L^* = 69.34$; $a^* = 17.08$; $b^* = 42.83$). On use of 6% pomegranate extract before dyeing the shade is darker having reddish yellow tone ($L^* = 71.89$; $a^* = 2.02$; $b^* = 34.64$), whereas 6% of pomegranate extract after dyeing has given darker shade with reddish yellow hue ($L^* = 70.27$; $a^* = 3.36$; $b^* = 32.45$).

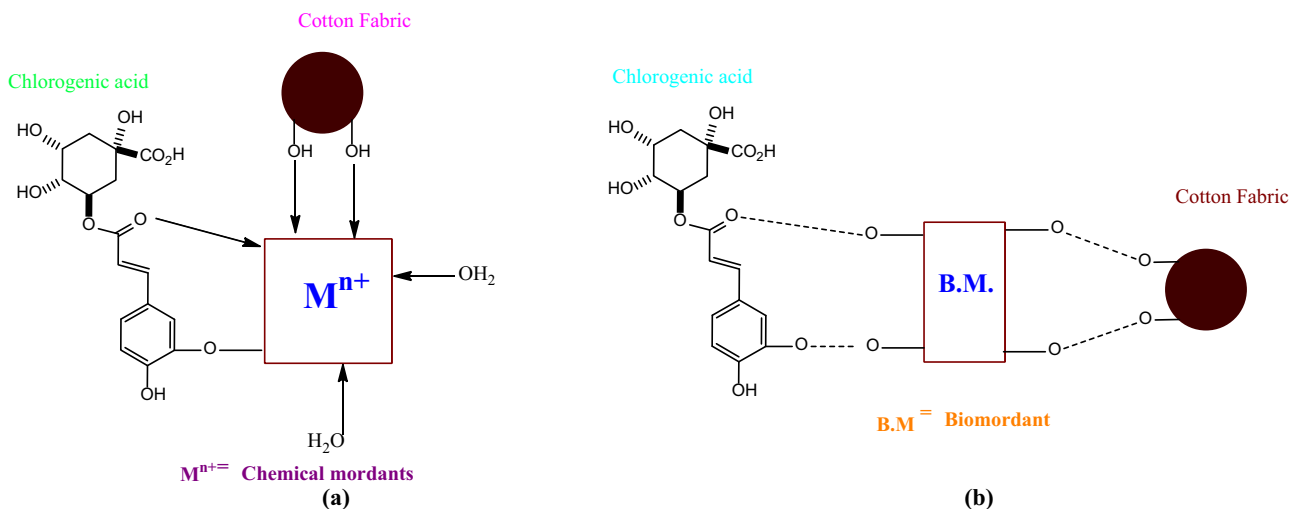
The fastness values in Table 2 reveal that before MW treatment, light washing and rubbing fastness were good. This is due to the fact that before use, the cotton fabric absorbed the colorant (chlorogenic acid) in the form of aggregates and binding firmly. Upon assessment under ISO standards, the color was detached, and good to poor ratings were observed (Table 2). After MW treatment of extract and fabric, the use of chemical and plant phenolic of turmeric, pomegranate as bio-stabilizers have produced excellent light and washing as well as good rubbing ratings. This is because $-OH$ from turmeric (curcumin), $-OH$ from pomegranate (tannin) interact with $-OH$ of cotton and functional site of colorant (chlorogenic acid) has developed colorfast shades. The additional H-bonding, conjugated structure by bio-mordants and tanning of cotton surface have also the role of high strength played in developing good shades of high strength. Hence, MW rays have not only added value in isolation of colorant but also addition of

Table 2 Shade variables and colorfastness ratings of chemical mordanted cotton fabric dyed using an acid-solubilized extract of coffee

Mordants used	L^*	a^*	b^*	Light fastness	Washing fastness	Rubbing fastness	
						Dry	Wet
Pre-mordanting							
Without mordant	61.87	4.45	16.58	3/4	3	3/4	3
Fe 2%	75.06	8.55	17.14	5	4/5	5	4/5
Tannic acid 10%	72.89	9.12	15.36	5	4/5	5	4/5
Sodium potassium tartrate 2%	89.44	1.31	12.02	5	4/5	5	4/5
Pomegranate 6%	71.89	2.02	34.64	5	5	5	4/5
Turmeric 4%	72.41	12.98	45.98	5	5	5	4/5
Post-mordanting							
Fe 4%	75.52	7.80	22.28	5	4/5	5	4/5
Tannic acid 10%	69.52	10.35	18.09	5	4/5	5	4/5
Sodium potassium tartrate 6%	87.80	2.06	12.97	5	4/5	5	4/5
Pomegranate 6%	70.27	3.36	32.45	5	5	5	4/5
Turmeric 10%	69.34	17.08	42.83	5	5	5	4/5

Notes: L^* = lighter/darker; a^* = redder/greener; b^* = yellower/bluer

Figure 9 Interaction of chemical (a) and bio-mordants (b) with chlorogenic acid and cotton



sustainable mordants have made natural dyeing more eco-friendly and colorfast.

Conclusion

Natural products in textiles having anti-viral and anti-bacterial nature are gaining worldwide fame, particularly their importance is raising in the pandemic scenario. Of these products, coffee beans is an excellent plant with better coloring potential for textiles. Addition of MW radiations as extraction tool for chlorogenic acid as brown natural colorant and the application of bio-molecules to get colorfast shades of better quality have not only made the process more eco-friendly but also soothing, ayurvedic and attractive for global community. The results show that irradiation of fabric for dyeing with coffee filtrate containing 5% of table salt at 80°C for 50 min, followed by sustainable mordanting has given acceptable shade strength and fastness ratings. It is concluded that MW rays have not only the potential to isolate colorant but also the application of bio-mordants have made the process more-greener, sustainable and cleaner.

References

- Abdelileh, M., Ticha, M.B. and Meksi, N. (2021), "Reviving of cotton dyeing by Saxon blue: application of microwave irradiation to enhance dyeing performances", *Fibers and Polymers*, Vol. 22 No. 7, pp. 1863-1873.
- Adeel, S., Hasan, M.U., Batool, F., Ozomay, M., Hosseinezhad, M., Amin, N. and Hussaan, M. (2022), "Eco-friendly bio-dyeing of bio-treated nylon fabric using esfand (*P. harmala*) based yellow natural colorant", *Journal of Engineered Fibers and Fabrics*, Vol. 17, pp. 1-15.
- Adeel, S., Rehman, F., Pervaiz, M., Hussaan, M., Amin, N., Majeed, A. and Rehman, H. (2021b), "Microwave assisted green isolation of laccic acid from Lac insect (*kerria lacca*) for wool dyeing", *Progress in Color Colorants and Coatings*, Vol. 14 No. 4, pp. 293-299.

- Adeel, S., Salman, M., Usama, M., Rehman, F.U., Ahmad, T. and Amin, N. (2021c), "Sustainable isolation and application of rose petals-based anthocyanin natural dye for coloration of bio-mordanted wool fabric: short title: dyeing of bio mordanted wool with rose petal extract", *Journal of Natural Fibers*, pp. 1-15.
- Arain, R.A., Ahmad, F., Khatri, Z. and Peerzada, M.H. (2021), "Microwave assisted henna organic dyeing of polyester fabric: a green, economical and energy proficient substitute", *Natural Product Research*, Vol. 35 No. 2, pp. 327-330.
- Barani, H. and Maleki, H. (2020), "Red cabbage anthocyanins content as a natural colorant for obtaining different color on wool fibers", *Pigment & Resin Technology*, Vol. 49 No. 3, pp. 229-238.
- Batool, F., Adeel, S., Iqbal, N., Azeem, M. and Hussaan, M. (2022), "Sustainable natural coloring potential of bitter melon (*Momordica charantia* L.) residues for cotton dyeing: innovative approach towards textile industry", *Environmental Science and Pollution Research*, Vol. 29 No. 23, pp. 34974-34983.
- Borrás-Enríquez, A.J., Reyes-Ventura, E., Villanueva-Rodríguez, S.J. and Moreno-Vilet, L. (2021), "Effect of ultrasound-assisted extraction parameters on total polyphenols and its antioxidant activity from mango residues (*Mangifera indica* L. var. Manililla)", *Separations*, Vol. 8 No. 7, pp. 1-18.
- Bukhari, M.N., Shabbir, M., Rather, L.J., Shahid, M., Singh, U., Khan, M.A. and Mohammad, F. (2017), "Dyeing studies and fastness properties of brown naphthoquinone colorant extracted from *Juglans regia* L on natural protein fiber using different metal salt mordants", *Textiles and Clothing Sustainability*, Vol. 3 No. 1, pp. 1-9.
- Buyukakinci, Y.B., Guzel, E.T. and Karadag, R. (2021), "Organic cotton fabric dyed with dyer's oak and barberry dye by microwave irradiation and conventional methods", *IndustriaTextila*, Vol. 72 No. 1, pp. 30-38.

- Chiari, B.G (2014), “Synergistic effect of green coffee oil and synthetic sunscreen for health care application”, *Industrial Crops and Products*, Vol. 52, pp. 389-393.
- Elabid, A.E.A., Ahmed, M.A., Asad, R.A. and Abdalnoor, O. A. (2021), “Dyeing properties of cotton fabrics using extracted dyes from Ethiopian and Congolese coffee”, *Journal of Engineering and Computer Science (JECS)*, Vol. 22 No. 2, pp. 1-8.
- El-Khatib, E.M., Ali, N.F., Nassar, S.H. and El-Shemy, N.S. (2021), “Functionalization of natural fibers properties by using TiO₂ nanoparticles to improve its antimicrobial activity”, *Biointerface Research in Applied Chemistry*, Vol. 12 No. 3, pp. 4177-4191.
- Fadil, M., Bousta, D., El Ouali Lalami, A., Lachkar, M. and Farah, A. (2021), “Ultrasound-assisted extraction of phenolic compounds from Moroccan *lavandula stoechas* L.: optimization using response surface methodology”, *Journal of Chemistry*, Vol. 2021, doi: [10.1155/2021/8830902](https://doi.org/10.1155/2021/8830902).
- Geelani, S.M., Ara, S., Mir, N.A., Bhat, S.J.A. and Mishra, P. K. (2017), “Dyeing and fastness properties of *Quercus robur* with natural mordants on natural fibre”, *Textiles and Clothing Sustainability*, Vol. 2 No. 1, pp. 1-10.
- Habib, N., Adeel, S., Ali, F., Amin, N. and Khan, S.R. (2021), “Environmental friendly sustainable application of plant-based mordants for cotton dyeing using Arjun bark-based natural colorant”, *Environmental Science and Pollution Research*, Vol. 28 No. 38, pp. 54041-54047.
- Haji, A. and Vadood, M. (2021), “Environmentally benign dyeing of polyester fabric with madder: modelling by artificial neural network and fuzzy logic optimized by genetic algorithm”, *Fibers and Polymers*, Vol. 22 No. 12, pp. 3351-3357.
- Handayani, P.A., Chafidz, A., Ramadani, N.S. and Kartika, D. (2019), “Microwave assisted extraction (MAE) process of tannin from mangrove propagules waste as natural dye for coloring batik tulis”, *Key Engineering Materials*, Vol. 805, pp. 128-133.
- Hao, Z.H., Zh. Antonio, D.T. and Vincenzo, F. (2019), “Melanoidins from coffee, cocoa, and bread are able to scavenge α -Dicarbonyl compounds under simulated physiological conditions”, *Journal of Agricultural and Food Chemistry*, Vol. 67 No. 39, pp. 10921-10929.
- Herlina, N. and Kurniati, A.S. (2020), “Coffee bean skin waste extraction for silk dyeing”, *IOP Conference Series: Materials Science and Engineering*, Vol. 801 No. 1, p. 012075.
- Hosen, M.D., Rabbi, M.F., Raihan, M.A. and Al Mamun, M. A. (2021), “Effect of turmeric dye and bio-mordants on knitted cotton fabric coloration: a promising alternative to metallic mordanting”, *Cleaner Engineering and Technology*, Vol. 3, p. 100124.
- Hosseinnezhad, M., Gharanjig, K., Jafari, R. and Imani, H. (2021), “Green dyeing of woolen yarns with weld and madder natural dyes in the presences of bio-mordant”, *Progress in Color Colorants and Coatings*, Vol. 14 No. 1, pp. 35-45.
- Islam, S.U., Rather, L.J., Shabbir, M., Bukhari, M.N., Khan, M.A. and Mohammad, F. (2018), “First application of mix metallic salt mordant combinations to develop newer shades on wool with bixa Orellana natural dye using reflectance spectroscopy”, *Journal of Natural Fibers*, Vol. 15 No. 3, pp. 363-372.
- Islam, S.U., Rather, L.J., Shabbir, M., Sheikh, J., Bukhari, M. N., Khan, M.A. and Mohammad, F. (2019), “Exploiting the potential of polyphenolic biomordants in environmentally friendly coloration of wool with natural dye from *butea monosperma* flower extract”, *Journal of Natural Fibers*, Vol. 16 No. 4, pp. 512-523.
- Jabar, J.M., Adedayo, T.E. and Odusote, Y.A. (2021), “Green, eco-friendly and sustainable alternative in dyeing cotton fabric using aqueous extract *mucuna slonaei* F dye: effects of metal salts pre-mordanting on color strength and fastness properties”, *Current Research in Green and Sustainable Chemistry*, Vol. 4, p. 100151.
- Jafari, S.M., Mahdavee Khazaei, K. and Assadpour, E. (2019), “Production of a natural color through microwave-assisted extraction of saffron tepal’s anthocyanins”, *Food Science & Nutrition*, Vol. 7 No. 4, pp. 1438-1445.
- Jong-Sup, J., Han-Taek, K., Il-Hyung, J., Se-Ra, H., Moon-Seog, O. and Mi-Hye, Y. (2019), “Contents of chlorogenic acids and caffeine in various coffee related products”, *Journal of Advanced Research*, Vol. 17, pp. 85-94.
- Khan, A.A., Adeel, S., Azeem, M. and Iqbal, N. (2021), “Exploring natural colorant behavior of husk of durum (*triticum durum* desf.) and bread (*Triticum aestivum* L.) wheat species for sustainable cotton fabric dyeing”, *Environmental Science and Pollution Research*, Vol. 28 No. 37, pp. 51632-51641.
- Koh, E. and Hong, K.H. (2019), “Preparation and properties of wool fabrics dyed with spent coffee ground extract”, *Textile Research Journal*, Vol. 89 No. 1, pp. 13-19.
- Kovačević, Z., Sutlović, A., Matin, A. and Bischof, S. (2021), “Natural dyeing of cellulose and protein fibers with the flower extract of *spartium junceum* l. plant”, *Materials*, Vol. 14 No. 15, p. 4091.
- Lee, K.O., Kim, H.J., Lee, H.J. and Hyeon, S.J. (2017), “Up-cycling natural dyeing using coffee sludge: dyeability study of coffee pigment”, *Fiber Technology and Industry*, Vol. 21, pp. 82-92.
- Mahdi, M.M., Tuj-Zohra, F. and Ahmed, S. (2020), “Dyeing of shoe upper leather with extracted dye from *acacia nilotica* plant bark an eco-friendly initiative”, *Progress in Color, Colorants and Coatings*, Vol. 14 No. 4, pp. 241-258.
- Majumder, J., Perinban, S. and Singh, B. (2020), “Effects of pre-treatment and microwave assisted extraction on natural dye from marigold (*tagetes erecta* L.) and nasturtium (*tropiolum majus* L.) for fabric colouration”, *International Journal of Chemical Studies*, Vol. 8 No. 3, pp. 514-521.
- Nam, C. and Xiang, C. (2019), “Natural dyeing application of used coffee grounds as a potential resource”, *International Journal of Fashion Design, Technology and Education*, Vol. 12 No. 3, pp. 335-345.
- Náthia-Neves, G., Vardanega, R. and Meireles, M.A.A. (2019), “Extraction of natural blue colorant from *genipa americana* L. using green technologies: techno-economic evaluation”, *Food and Bioproducts Processing*, Vol. 114, pp. 132-143.
- Nathia-Neves, G., Vardanega, R., Hatami, T. and Meireles, M.A.A. (2020), “Process integration for recovering high added-value products from *genipa americana* L.: process

- optimization and economic evaluation”, *The Journal of Supercritical Fluids*, Vol. 164, p. 104897.
- Prado, J.M., Veggi, P.C., Náthia-Neves, G. and Meireles, M. A.A. (2020), “Extraction methods for obtaining natural blue colorants”, *Current Analytical Chemistry*, Vol. 16 No. 5, pp. 504-532.
- Ranjha, M.M.A., Irfan, S., Lorenzo, J.M., Shafique, B., Kanwal, R., Pateiro, M. and Aadil, R.M. (2021), “Sonication, a potential technique for extraction of phytoconstituents: a systematic review”, *Processes*, Vol. 9 No. 8, p. 1406.
- Rather, L.J., Islam, S.U., Shabbir, M., Bukhari, M.N., Mohammad, F. and Khan, M.A. (2018), “Adhatoda vasica in conjunction with binary combinations of metal salts and biomordants as an effective textile dye to produce novel shades on wool”, *Journal of Natural Fibers*, Vol. 15 No. 4, pp. 611-623.
- Rather, L.J., Khan, M.A. and Mohammad, F. (2019), “Biomordanting potential of acacia nilotica (babul) in conjunction with kerria lacca and rheum emodi natural dyes”, *Journal of Natural Fibers*, Vol. 16 No. 2, pp. 275-286.
- Samant, L., Jose, S., Rose, N.M. and Shakyawar, D.B. (2020), “Antimicrobial and UV protection properties of cotton fabric using enzymatic pretreatment and dyeing with acacia catechu”, *Journal of Natural Fibers*, Vol. 19 No. 6, pp. 2243-2253.
- Seemork, K., Setthayanond, J., Suwanruji, P. and Tooptompong, P. (2020), “Utilization of spent coffee ground oil in eco-friendly scouring and reactive dyeing processes for cotton”, *Materials Science Forum*, Vol. 1005, pp. 85-92.
- Shabbir, M., Islam, S.U., Bukhari, M.N., Rather, L.J., Khan, M.A. and Mohammad, F. (2017), “Application of terminalia chebula natural dye on wool fiber-evaluation of color and fastness properties”, *Textiles and Clothing Sustainability*, Vol. 2 No. 1, pp. 1-9.
- Shabbir, M., Rather, L.J., Bukhari, M.N., Khan, M.A. and Mohammad, F. (2018), “First-time application of bio-

- mordants in conjunction with the alkanna tinctoria root extract for eco-friendly wool dyeing”, *Journal of Natural Fibers*, Vol. 16 No. 6, pp. 846-854.
- Swami, C., Saini, S. and Gupta, V.B. (2014), “Kinetic and diffusion studies of a dye extracted from sesbania aculeata plant”, *Pigment & Resin Technology*, Vol. 43 No. 3, pp. 118-126.
- Viera, I., Pérez-Gálvez, A. and Roca, M. (2019), “Green natural colorants”, *Molecules*, Vol. 24 No. 1, p. 54.
- Yusuf, M., Mohammad, F., Shabbir, M. and Khan, M.A. (2017), “Eco-dyeing of wool with rubia cordifolia root extract: assessment of the effect of acacia catechu as bio-mordant on color and fastness properties”, *Textiles and Clothing Sustainability*, Vol. 2 No. 1, pp. 1-9.
- Zayed, M., Ghazal, H., Othman, H. and Hassabo, A.G. (2021), “Psidium guajava leave extract for improving ultraviolet protection and antibacterial properties of cellulosic fabrics”, *Biointerface Research in Applied Chemistry*, Vol. 12 No. 3, pp. 3811-3835.
- Zheng, J., Wang, Y., Zhang, Q., Wang, D., Wang, S. and Jiao, M. (2021), “Study on structure and properties of natural indigo spun-dyed viscose fiber”, *e-Polymers*, Vol. 21 No. 1, pp. 327-335.

Further reading

- Adeel, S., Kiran, S., Shahid, M., Habib, S.R., Habib, N. and Hussaan, M. (2021a), “Ecofriendly application of coconut coir (cocos nucifera) extract for silk dyeing”, *Environmental Science and Pollution Research*, Vol. 29 No. 1, pp. 564-572.

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