International Journal of Home Science 2025; 11(3): 178-183

International Journal of Home Science

ISSN: 2395-7476
Impact Factor (RJIF): 5.66
IJHS 2025; 11(3): 178-183

www.homesciencejournal.com
Received: 19-08-2025
Accepted: 23-09-2025

Deepti Nitin Kothari
Ph.D. Scholar, Department of Clothing and Textiles, Faculty of Family and Community Sciences, the Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India

Dr. Hemlata Raval
Assistant Professor, Department of Clothing and Textiles, Faculty of Family and Community Sciences, the Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India

Corresponding Author:
Deepti Nitin Kothari
Ph.D. Scholar, Department of Clothing and Textiles, Faculty of Family and Community Sciences, the Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India

Advancing SDG 12 through eco discharge printing

Deepti Nitin Kothari and Hemlata Raval

DOI: https://www.doi.org/10.22271/23957476.2025.v11.i3c.1993

Abstract
This research investigates the potential of eco-discharge printing using acid cellulase enzyme as a sustainable alternative to conventional chemical discharge methods, aligning with the objectives of Sustainable Development Goal 12 (SDG 12) Responsible Consumption and Production. The study focuses on five natural dye shades, green, brown, red, blue, and dark blue, applied to modal fabric, a regenerated cellulosic textile known for its eco-friendly production. An experimental approach was employed to optimise the discharge print recipe by systematically varying key process parameters: pH, temperature, enzyme concentration, and time. Discharge-printed samples were evaluated using a spectrophotometer to determine the degree of colour removal and visual clarity. Among the tested shades, green and brown demonstrated good discharge results, with clearly defined print edges and minimal background staining. Traditionally, white discharge printing on dark-coloured backgrounds has relied on chemical agents like sodium formaldehyde sulphoxylate, which, although effective, pose serious environmental and health hazards due to the release of toxic sulphur-based compounds and formaldehyde in effluents. In contrast, the enzymatic discharge method using acid cellulase was found to be effective and eco-friendly. The optimally discharged samples in green and brown shades were further evaluated for tensile strength and fabric hand, confirming that the enzyme-based process maintained the mechanical and tactile properties of the fabric. Moreover, Chemical Oxygen Demand (COD) testing of the wastewater from the optimised enzymatic recipe showed emission levels within permissible environmental limits, highlighting its potential for safer industrial application. The study successfully demonstrates that acid cellulase enzyme can overcome the limitations of conventional chemical discharge agents in selected natural dye shades. By reducing the use of hazardous chemicals, minimizing water pollution, preserving fabric quality, and ensuring safety for both artisanal health and wearer skin contact, this method provides a viable pathway for advancing SDG 12 targets, particularly through sustainable resource management, cleaner production practices, and responsible textile design.

Keywords: Acid cellulase enzyme, discharge printing, modal fabric, natural dyes, sustainable development goals (SDG 12)

1. Introduction

Textile printing enhances fabric surfaces with colour and pattern, commonly through three methods: direct, discharge, and resist printing. Discharge printing is unique, as the fabric is first dyed and then treated with a chemical agent that selectively removes colour in specific areas to form a design. This can produce white discharge, revealing the underlying fabric for bright, crisp motifs, or coloured discharge, where new pigments replace the removed dye to create contrasting designs. Typically, the fabric is dyed with a reducible dye, and a discharge paste is printed onto the desired areas. During steaming, the agent breaks down the dye only in the printed regions, which is later removed by washing, leaving behind the intended motifs. The success of this method depends on choosing a discharging agent compatible with both the fibre and dye class (Haggag *et al.* 2013) [3].

In textile printing, various substances can act as discharging agents, including salts, acids, alkalis, and oxidising or reducing compounds, with formaldehyde sulfoxylates and thiourea dioxide being the most common. However, conventional discharge methods often leave formaldehyde residues exceeding the 75 ppm limit for skin-contact textiles set by Oeko-Tex Standard 100, raising concerns for human health and the environment. As a result, enzyme-based alternatives have gained attention as a more sustainable and eco-friendly approach to textile processing (Karthikeyan and Dhurai 2011) [6].

Enzymes are protein-based biological catalysts composed of amino acid chains, generally represented as NH_2-R-COOH. While they do not initiate reactions themselves, enzymes significantly accelerate chemical processes on substrate surfaces and facilitate these transformations without being consumed, making them highly efficient and reusable (Haggag *et al.* 2013) [3]. Acid cellulase, a specialized cellulase enzyme, acts on cellulose fibers by breaking down surface chains, disrupting dye-binding sites, and enabling effective dye removal. Its broad applicability allows precise, well-defined discharge patterns across different dye types. However, excessive treatment or high enzyme activity can compromise fabric integrity, causing unwanted degradation.

In recent years, natural dyes have regained importance in textiles. India's rich biodiversity provides abundant resources for eco-friendly, skin-safe dyes. Growing awareness of the health and environmental risks of synthetic dyes has further increased interest. The revival of traditional dyeing preserves cultural heritage and supports rural livelihoods, while conservation efforts and scientific advancements improve the efficiency and consistency of natural dyeing, making it both environmentally sustainable and culturally significant (Samanta 2024) [8].

Natural dyes contain functional groups such as -OH, -NH_2, and -COOH, which can interact with active sites on textile fibers (-OH, -SO_3H, -COOH, -C_6H_5OH, -NH_2), either directly or with mordants, forming strong dye-fiber bonds. These interactions enhance colour fastness and fabric durability while imparting additional functional benefits. Depending on the dye's chemistry tannins, flavonoids, or anthraquinones textiles may gain antimicrobial and antibacterial properties, UV protection, deodorizing effects, and resistance to moths, insects, and mosquitoes (Jahan 2020) [5].

This study addresses the growing interest in natural dyes by exploring the use of acid cellulase in discharge printing as a safer, more sustainable alternative to formaldehyde sulfoxylate. Focusing on modal fabrics, it examines the enzyme's ability to selectively remove natural dyes, promoting eco-friendly textile processing. Beyond technical outcomes, the research highlights the integration of green practices into fabric design and finishing. Aligned with sustainable development goal 12 responsible consumption and production it underscores the importance of reducing hazardous chemicals, optimising resources, and supporting cleaner, sustainable production in the textile industry.

2. Objective

To evaluate enzyme discharge printing on natural dyed modal fabrics as a sustainable alternative, assessing its effects on discharge efficiency, fabric quality, and environmental impact.

3. Delimitation

The study was limited to the use of five natural dye shades on modal fabric, employing acid cellulase enzyme for the discharge printing process.

4. Materials and Methods

The experimental research methodology was followed for the study

4.1. Procure natural-dyed modal fabrics from the craft sector: The most widely produced natural-dye shades were procured from the craft sector 'Bargad Hand Print', based in Akola, Chota Udaipur and Rajasthan. Five shades of natural dyes were procured on modal fabric, which included red, brown, green, blue, and dark blue.

4.2 Preliminary data

4.2.1 Preliminary data of undyed fabric: The undyed modal fabric was tested for its preliminary tests, like fiber content (microscopic test, burning test, and chemical test), fabric weave, fabric count, fabric weight, and fabric thickness.

4.2.2 Preliminary data of dyed fabric: The procured five natural dyed fabrics were tested for their CIE L*a*b* values and the presence of the type of chromophore structure on the modal fabric with the help of a Fourier Transform Infrared Spectroscopy (FT-IR) test of the dyed fabrics.

4.3 Optimisation of discharge print

Acid cellulase enzyme was used principally to experiment with the discharge printing on natural dyed modal fabric. The entire discharge printing process involved creating the discharge print paste, printing with the aid of the stencil printing technique, treating the printed samples by padding them between two layers of muslin, steaming, and finally washing the samples with fresh water and allowing them to dry at ambient room conditions.

The enzyme-based discharge print recipe was optimized by exploring various variables, including pH, treatment temperature, enzyme concentration, and treatment time.

4.4 Testing of discharge print: The discharge print was tested for its L* values under a spectrophotometer, tensile strength, and effluent release in wastewater through the Chemical Oxygen Demand test, and hand.

4.4.1 Spectrophotometer: After performing the discharge printing for optimisation of the discharge print recipe on the five procured natural dyed shades of modal fabric, the samples were tested for their L* values on the Premier 5100 spectrophotometer. Undyed modal fabric was kept as the standard sample for the test.

4.4.2 Tensile strength: During the discharge printing process, the discharging agent also acts on the fabric while discharging the dye that is bonded to it. So, it becomes crucial to measure the deterioration caused to the tensile strength of the fabric, ensuring the final product will withstand wear and tear. ASTM D5035 was performed on a Universal Tensile Tester, model 1121, where a tensile force was applied to the sample at a constant rate of extension to measure the sample properties under stress. Here, the undyed fabric was kept as standard.

4.4.3 Chemical Oxygen Demand: Testing of the wastewater after performing the discharge printing process for its Chemical Oxygen Demand becomes important as it measures the oxygen depletion it will cause to the environment to chemically oxidize the organic and inorganic substances present in wastewater. APHA 24th Edition 2023-5220 B test method was followed to test the Chemical Oxygen Demand in wastewater. This test would ultimately help determine whether the wastewater emissions that result from the discharge printing process are sustainable, as they directly impact ecosystem health.

4.4.4 Hand: The discharge-printed samples were subjectively evaluated to assess variations in surface texture, specifically in terms of smoothness or coarseness, in comparison to the corresponding dyed fabric.

5. Findings and Discussion

5.1. Procure natural-dyed modal fabrics: The widely produced five natural-dye shades on modal procured from the craft sector 'Bargad Hand Print', based in Akola, Chota Udaipur, Rajasthan, were mordanted with harda and dyed with the following natural dye combinations given in Table 1.

Table 1: Natural dyes used in the dyeing of modal fabric

Sr. No.	Shade	Natural dye used
1.	Red	Alizarin
2.	Brown	Iron Rust
3.	Green	Pomegranate Rind
4.	Blue	Indigo
5.	Dark Blue	Indigo + Pomegranate Rind

5.2. Preliminary data

5.2.1 Preliminary data of undyed fabric

Table 2: Fiber content of undyed fabric

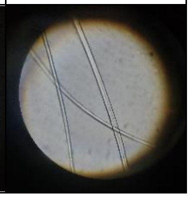
Fabric	Burning		Solubility		Microscopic	
	Warp	Weft	Warp	Weft	Warp	Weft
Modal	Ignites on contact with flames; burns quickly. Does not melt. Continue to burn for a short while after removal from flame. It has the odor of burning paper, leaves, or wood. The residue is light fluffy grey ash that can be easily crushed.		Soluble in 70% Sulfuric acid			

Table 3: Preliminary data of undyed fabric

Fabric	Fiber Content	Weave of the Fabric	Fabric Count (Threads/sq. inch)		Weight per unit area (gms/sq. mt)	Fabric thickness (cm)
			Ends	Picks		
Modal	100% Modal	Plain Weave	94	80	40.19	0.18

5.2.2 Preliminary data of dyed fabric

Table 4: CIE L*a*b* values of the five natural dyed modal fabrics

Shade	L*	a*	b*	c*	DL*	dE*
Undyed Modal	69.340	-0.309	1.936	1.961	-	-
Red	16.369	43.598	28.207	51.927	-52.971	73.647
Brown	1.442	7.322	2.470	7.727	-67.898	68.328
Green	43.312	4.054	45.160	45.342	-26.028	50.644
Blue	0.944	12.828	-25.168	28.249	-68.396	74.734
Dark Blue	0.009	0.000	0.000	0.000	-69.331	69.359

The presence of the type of chromophore structure of natural dye with modal fabric was determined with the help of an FT-IR test. Undyed modal fabric was kept as a standard for analysis of the dyed samples.

- **Red:** FTIR analysis of alizarin-dyed modal fabric showed a broad peak at 3300-3400 cm^{-1}, suggesting hydrogen bonding between dye molecules and fabric -OH groups. A shift at 1601.79 cm^{-1} indicates interactions involving carbonyl or C=C groups. Changes at 1157.29 cm^{-1} and 1026.13 cm^{-1} may involve C-O bonds, while new peaks at 686.66 cm^{-1} and 501.49 cm^{-1} confirm aromatic structures. Overall, dye-fabric interactions likely involve Van der Waals forces, hydrogen bonding, and ionic bonding.
- **Brown:** FTIR analysis of modal fabric mordanted with harda and dyed with iron rust showed a broad peak at 3200-3600 cm^{-1}, indicating O-H groups from cellulose and dye. A sharp peak at 1700-1750 cm^{-1} suggests C=O stretching and hydrogen bonding or dipole interactions. Peaks at 1600-1650 cm^{-1} and 600-800 cm^{-1} indicate aromatic/azo groups, while Fe^{3+}-O vibrations around 500-600 cm^{-1} suggest coordination between Fe^{3+} ions and fabric functional groups. Overall, interactions likely include Van der Waals forces, hydrogen bonding, and ionic bonding.
- **Green:** FTIR analysis of modal fabric dyed with pomegranate rind showed a broad 3200-3600 cm^{-1} peak (O-H stretching) indicating hydrogen bonding. Peaks at 1700-1750 cm^{-1} (C=O) and 1600-1650 cm^{-1} (aromatic C=C) confirm dye incorporation, while 1000-1300 cm^{-1} (C-O) and 600-800 cm^{-1} (aromatic bending) suggest phenolic structures. Dye-fabric interactions likely involve Van der Waals forces, π-π stacking, hydrogen bonding, and ionic bonding.
- **Blue:** FTIR analysis of indigo-dyed modal fabric showed peaks at 3200-3500 cm^{-1} (O-H/N-H stretching) and 1600-1700 cm^{-1} (C=O stretching), indicating hydrogen bonding and carbonyl involvement. Peaks at 1400-1500 cm^{-1} and 1000-1200 cm^{-1} suggest aromatic/N=N chromophores and C-O stretching. Dye-fabric interactions likely include Van der Waals forces, π-π stacking, hydrogen bonding, and covalent bonding.
- **Dark Blue:** FTIR analysis of indigo + pomegranate rind-dyed modal fabric showed peak shifts at 3200-3600 cm^{-1} (O-H/N-H), 1650-1750 cm^{-1} (C=O), and 1500-1600 cm^{-1} (C=C/N=N), indicating hydrogen bonding, dipole interactions, and chromophore retention. Peaks at 1000-1300 cm^{-1} suggest sulfonate groups and electrostatic dye-fiber bonding. Interactions likely include π-π stacking, hydrogen bonding, ionic bonding, and mixed metal complexes.

5.3 Optimisation of discharge print: Enzymes need specific environmental conditions to work optimally. These include factors like pH and temperature. Acid cellulase enzyme, as the name suggests, would work optimally in acidic pH. Lemon juice was used to maintain the acidity of the discharge printing paste. Treatment temperature, concentration of enzyme, and treatment time were the other variables experimented with for the optimisation of the discharge print paste for the five shades of natural dyed modal fabrics. The parameters of the variables have been listed in the table below:

Table 5: Variables used in the discharge print paste

Sr. No.	Variable	Parameters
1.	pH	5.2 pH, 4.9 pH, 4.6 pH, 4.3 pH, 4 pH, 3.7 pH
2.	Treatment Temperature	40-45 °C, 45-50 °C, 50-55 °C, 55-60 °C
3.	Enzyme Concentration	7.5%, 10%, 12.5%, 15%
4.	Treatment Time	45 mins, 60 mins, 75 mins, 90 mins

5.4 Testing of discharge print
5.4.1 Spectrophotometer

Table 6: Measurement of L* values for pH optimisation

pH	Red	Brown	Green	Blue	Dark Blue
	L*	L*	L*	L*	L*
Undyed fabric	69.340	69.340	69.340	69.340	69.340
5.2 pH	18.687	24.648	49.137	4.469	1.004
4.9 pH	18.916	26.393	49.735	6.047	0.172
4.6 pH	21.976	29.643	52.436	3.707	0.258
4.3 pH	21.392	27.884	52.243	3.399	0.871
4 pH	22.653	33.974	50.758	3.071	0.841
3.7 pH	26.338	33.724	54.819	2.447	0.609

In Table 6, it could be observed that effective discharge print was noticeable in brown and green dyed modal fabrics. Red showed a tone-in-tone effect, whereas blue and dark blue did not show any significant discharge effect at all. Optimum pH was 4 pH for the brown shade, while 3.7 pH for the green shade of natural dyed modal.

Table 7: Measurement of L* values for treatment temperature optimisation

Treatment Temperature	Red	Brown	Green	Blue	Dark Blue
	L*	L*	L*	L*	L*
Undyed fabric	69.340	69.340	69.340	69.340	69.340
40-45 °C	19.153	32.463	53.090	3.482	0.395
45-50 °C	20.757	31.339	54.999	3.872	1.293
50-55 °C	17.699	28.480	49.476	4.027	0.869
55-60 °C	18.658	29.183	50.846	3.642	0.407

As in Table 7, a prominent discharge print effect was visible in brown and green shades of natural dyed modal. Red again produced a tone-in-tone effect, while blue and dark blue shades still could not show any significant discharge effect. The optimum temperature found for discharge printing was 40-45 °C for brown and 45-50 °C for green shade of natural dyed modal fabric.

Table 8: Measurement of L* values for enzyme concentration

Enzyme Concentration	Red	Brown	Green	Blue	Dark Blue
	L*	L*	L*	L*	L*
Undyed fabric	69.340	69.340	69.340	69.340	69.340
7.5%	17.493	22.991	51.774	4.455	0.567
10%	17.090	21.200	50.358	4.281	0.770
12.5%	17.429	21.717	51.649	4.544	0.597
15%	16.349	24.461	49.911	5.851	0.487

According to the results in Table 8, optimum enzyme concentration was found to be 15% for brown shade and 7.5% for green shade. As mentioned earlier, red, blue, and dark blue shades of natural dyes could not be discharged significantly with the help of acid cellulase enzyme.

Table 9: Measurement of L* values for treatment time optimisation

Treatment Time	Red	Brown	Green	Blue	Dark Blue
	L*	L*	L*	L*	L*
Undyed fabric	69.340	69.340	69.340	69.340	69.340
45 min	19.918	34.513	53.324	5.021	1.755
60 min	20.683	37.492	54.624	4.615	2.177
75 min	23.130	36.732	54.705	4.048	2.382
90 min	19.927	39.764	51.804	2.920	1.533

Table 9 reflects that the optimum treatment time was 90 minutes for the brown shade and 60 minutes for the green shade of the natural dyed modal fabric. No significant discharge was seen in red, blue, and dark blue shades.

Table 10: Optimised discharge print recipe variables

Variables	Brown	Green
pH	4 pH	3.8 pH
Temperature	40-45 °C	45-50 °C
Concentration	15%	7.5%
Time	90 mins	60 mins

The red, blue, and dark blue natural-dyed shades on modal fabric did not yield satisfactory discharge results and were excluded from further tests. The red shade with alizarin and indigo-dyed fabrics likely resisted discharge due to strong dye-fiber bonds that acid cellulase hydrolysis could not break. Additionally, indigo is applied in an alkaline medium, making the acidic conditions of the enzyme paste unsuitable for its reduction.

Table 11: Optimised discharge print recipe

Ingredients	Quantity
Acid cellulase enzyme	75/150 grams
Lemon juice	72/83 grams
Sodium alginate	100 grams
Water	Y grams
Total	1000 grams

5.4.2. Tensile strength test: Tensile strength test of the samples giving the optimum results of discharge print were tested. These included the brown and green shades of natural dyes on modal fabric. The table below shows the results of the tensile strength test of warp and weft in percentage of standard (undyed) modal fabric, dyed fabric, and discharge printed fabric with optimised recipe

Table 12: Tensile strength

Sample	Maximum load (kgf)			
	Warp	% Warp	Weft	% Weft
Standard (Undyed)	1.413	100	1.12	100
Brown dyed	0.772	55	0.644	58
Brown discharge printed	0.767	54	0.848	76
Green dyed	0.885	63	0.932	83
Green discharge printed	1.079	76	0.914	82

The primary role of acid cellulase is the hydrolysis of cellulose, particularly at the fabric surface. In textile applications, this enzymatic action is harnessed in the biopolishing of cellulosic materials, where it effectively minimises surface hairiness and enhances the smoothness of the fabric, thereby improving both its aesthetic appeal and tactile quality.

In discharge printing with acid cellulase, natural-dyed modal fabric undergoes surface hydrolysis, breaking the bonds between fibers and dye chromophores to create a bio-discharge print. This controlled enzymatic action enables environmentally friendly discharge effects while potentially affecting fabric strength, underscoring the need to balance print quality with durability.

As shown in Table 12, brown and green dyed fabrics initially exhibited a reduction in tensile strength compared to undyed modal. Following discharge printing with acid cellulase, tensile strength was maintained or improved. For brown, warp strength remained largely unchanged, while green weft strength was similar to the original. Notably, brown weft and green warp showed a 13-18% increase, attributed to the enzyme's gentle, selective hydrolysis of dye molecules without damaging fibers. The mild treatment may also have provided a biopolishing effect, removing surface fibrils and distributing stress more evenly, enhancing tensile performance. In contrast, conventional chemical discharge agents are harsher, often causing fiber degradation and further strength loss.

5.4.3. Chemical Oxygen Demand:

Table 13: Chemical Oxygen Demand (COD) of optimised discharge print paste in wastewater

Sample	Test Parameter	Result	Desirable Limit
Waste water of the acid cellulase enzyme optimised discharge print recipe.	COD	63.36 mg/L	250 mg/L

The test results, 63.36 mg/L, were found to be well under the desirable limits set for the effluent in wastewater. Formaldehyde, a known carcinogen found in the traditional discharge printing agents, could now be completely replaced with discharge printing with the use of acid cellulase enzyme for specific natural dyes. All the ingredients used in the discharge printing paste-acid cellulase enzyme, lemon juice, sodium alginate, and water are friendly, making the whole process sustainable.

5.4.4. Hand

In the subjective assessment of fabric hand, the discharge-printed modal treated with acid cellulase was perceived as smoother compared to the original dyed fabric.

6. Summary and Conclusion

This study highlights enzyme-assisted discharge printing as a sustainable alternative to conventional chemical methods. Replacing hazardous agents like formaldehyde sulfoxylate with acid cellulase significantly reduces the environmental impact of textile production. Among the natural dyes tested, green produced the clearest and most visually appealing discharge effects while maintaining fabric integrity, followed by brown.

A major environmental advantage of this method is its effluent profile: wastewater from the enzyme-assisted process had COD values within permissible limits and, unlike chemical discharge printing, contained no formaldehyde. This highlights the eco-friendly nature of the technique, which achieves precise tone-on-tone colour removal (except for alizarin and indigo) without affecting fabric quality.

The study also demonstrates the potential for a fully sustainable product range, with modal fabric a renewable, biodegradable fibre dyed with natural dyes and eco-discharge printed using acid cellulase. This closed-loop approach aligns with UN Sustainable Development Goals, particularly SDG 12 (Responsible Consumption and Production) by reducing toxic inputs, and SDG 6 (Clean Water and Sanitation) by lowering wastewater pollutants. Broadly, it supports the fashion industry's move toward circular models that emphasise resource efficiency, waste reduction, and textile longevity, promoting "commerce with conscience".

7. Implications and Suggestions

The study shows that enzyme-assisted discharge printing with acid cellulase is an efficient and sustainable discharge printing method that improves fabric smoothness and strength while reducing environmental impact. It is suggested to explore different enzyme types for the effective discharge of dyes like alizarin and indigo from modal fabric.

8. Acknowledgement

The modal fabric was sponsored by Birla Cellulose for the research study.

References

1. Chattopadhyay SN, Sanyal SK. Enzyme treatment on jute-effect of resin treatment. Colourage. 2001;48:20.
2. Dhurai K, Bharathi D. New method of discharge printing on cotton fabrics using enzymes. Fibre2Fashion. 2012 Mar 26. Available from: https://www.fibre2fashion.com/industry-article/6139/new-method-of-discharge-printing-on-cotton-fabrics-using-enzymes
3. Haggag K, Ragheb A, El-Thalouth I, Nassar S, El-Sayed H. A review article on enzymes and their role in resist and discharge printing styles. Life Sci J. 2013;10:1646-1654.
4. Heine E, Hoecker H. Smart fibres, fabrics and clothing. In: Tao X, editor. Smart fibres, fabrics and clothing. Boca Raton: CRC Press; 2001, p. 254.
5. Jahan S. Functional properties of natural dyed textiles. Academia.edu; 2020 Jan. Available from: https://www.academia.edu/70572460/Functional_Properties_of_Natural_Dyed_Textiles
6. Karthikeyan K, Dhurai B. New method of discharge printing on cotton fabrics using horseradish peroxidase. Autex Res J. 2011;11(2):61-65. https://doi.org/10.1515/aut-2011-110206
7. Kumar A, Chowdhury AKR. Eco-friendly dyes and dyeing. Adv Mater Technol Environ Sci. 2018;2(1):145-176.
8. Samanta AK. Fundamentals of natural dyeing of textiles: pros and cons. Caluniv; 2024 Dec. Available from: https://www.academia.edu/47123015/fundamentals_of_natural_dyeing_of_textiles_pros_and_cons?email_work_card=view-paper