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Research article

Analyzing different functional and dyeing performance of natural blended fabric utilizing natural dyes and quality prediction by fuzzy logic

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ABSTRACT

This research evaluated ways for applying natural dyes, such as pomegranate peels, marigold flowers, and turmeric separately, to dye hybrid fabric made of cotton and jute. Natural dyes provide a harmless alternative to synthetic dyes, which support the sustainable properties of cotton and jute. Applying natural dyes, such as the dye extracted from pomegranate peels, can reduce wastes. The research analyzed the performance of natural dyes on jute-cotton blended fabric. A different approach that was studied was fuzzy logic as a potential indicator of fabric quality based on dyeing factors. Every colored item was indicated acceptable color fastness to rubbing and washing. Turmeric (Curcuma longa) obtained a score of 3, marigold (Tagetes erecta) flowers earned a score of 3/4, and pomegranate (Punica granatum) peels received a score of 4 for color fastness to wash. SEM images exhibited a fibrous structure that was extremely packed and included a Y-shaped fiber break. With an emission at 1639 cm^{-1}, FTIR showed carbonyl groups. Pomegranate peels obtained best quality rating of 87.4 %. Color permanence made it feasible and non-toxic substitute for artificial dyes. The tensile force of dyed fabric with pomegranate peels improved by 15 %. The objective of the research is the replacement of synthetic dyes in a sustainable way.

1. Introduction

The textile industry is always fighting for a balance between environmental effect, sustainability, and quality [1]. Synthetic dyes raise issues with respect to toxicity, allergic reactions, and environmental contamination despite providing brilliant colors and reliable results [2]. At the same time, it is challenging to achieve consistent shades, color fastness, and repeatability with natural dyes [3]. It is feasible to develop a more accurate and dependable method of predicting the quality of naturally dyed fabrics by using fuzzy logic [4]. Good-quality fabric helps with sustainable development [5]. It involves protecting in addition to the safety of the planet's ecosystems and inhabitants, but also their health [6]. Sustainable materials, environmentally friendly production processes, and durable patterns are attributes of outstanding textiles [7]. For achieving good-quality fabrics, fuzzy logic helps to fix the parameters accordingly [8]. Natural dyes have wide application in the coloration of most of the natural fibers, e.g., cotton, linen, wool, and silk fiber, and to some extent for nylon and polyester synthetic fiber [9]. However, the major issues for natural dyed textiles are the reproducibility of shade, the non-availability of well-defined standard procedures for application, and the poor lasting performance of shade under water and

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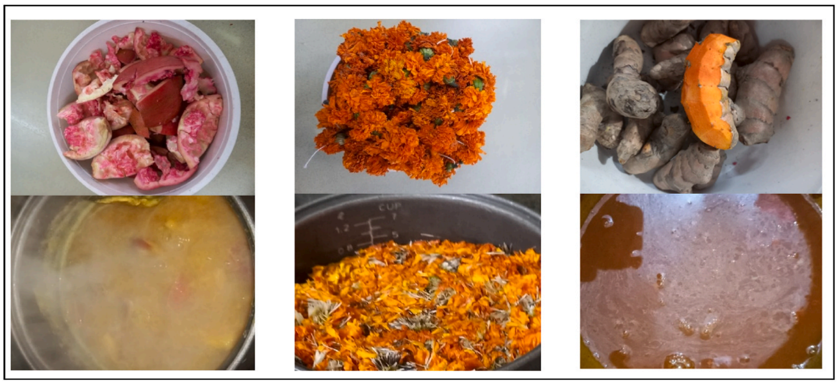
light exposure [10]. To achieve good color fastness, washing and light are also challenges for the dye [11]. On the other hand, natural dyes can produce amazingly vivid colors when mixed properly and are non-toxic and non-allergic [12]. The plants used to make the colors to produce no waste because the rest of the plant is used in a variety of ways by the local population, such as for medical purposes, cooking, or food scraps [13]. Natural dyes have fewer reactive groups in their terminal parts to react with the fibers and the dye molecules; therefore, they provide very few colorfastness properties [14]. The cellulosic fibers are somewhat tough to dye with natural color since they have very poor attraction and substance [15]. Due to this scarcity of reactivity with the fibers and dyes, mordents are mandatory [16]. When wearing garments colored with remedial plants, our body can take advantage of their healing characteristics by being engrossed in the skin [17]. Contrariwise, our bodies also engross poisonous chemicals from artificial dyes [18]. It's worth seeing not only what we bother with for our health but also the fabric we costume next to our covering [19]. Whatever is chosen for the dye pot can be replanted for an incessant source of dyed material [20]. The purpose of this study is to evaluate the efficiency and flexibility of natural dyes on blends of jute and cotton while utilizing fuzzy logic to predict the quality of the dyes depending on important characteristics [21]. The colorfastness of natural colors derived from marigold flowers (*Tagetes erecta*), pomegranate peels, and turmeric on cotton-jute hybrid fabrics were evaluated in this paper. With an assessment of their performance in terms of color fastness and fabric quality, it aims to illustrate the sustainability of natural wastages like pomegranate peels as sustainable substitutes for synthetic dyes [22]. In order to predict fabric quality based on dyeing factors, the research uses fuzzy logic, which produces reliable and consistent results [23]. It additionally encourages eco-friendly methods of textile manufacturing while emphasizing the possible health benefits of employing naturally colored textiles [24]. Again, this study aims to leverage fuzzy logic to predict the quality of naturally dyed jute-cotton fabrics, improving reproducibility, application methods, and light/water fastness, ultimately fostering sustainable. The ultimate objective of the research is to aid in the manufacturing of superior, eco-friendly fabrics [25]. This investigation covers in significant knowledge gaps in textile dyeing by focusing on the health and environmental risks related to synthetic dyes and emphasizing their toxicity and recycling concerns [26]. It also attracts attention to the irregularities in natural dyeing, particularly when it relates to achieving color fastness and uniformity. This research solves a research gap concerning natural dyes for blended fabrics such as cotton and jute. Additionally, it shows fuzzy logic as an innovative method to assess spontaneously dyed materials, fulfilling the need for systematic assessment techniques. Finally, the research recommends the use of natural wastages like pomegranate peels as organic dyes in textile manufacturing as a healthy, sustainable replacement. The two modern methods of radiation for boosting the absorption of dye and increasing color fastness are ultraviolet and gamma radiation [27]. Without the use of toxic substances, energy can change the surface features of fibers, increasing their attraction to dyes. Plasma is an incredibly strong non-toxic treatment that is used to change the surface of both synthetic and natural fibers [28]. It aids dyeing without impacting the primary features of the fabric by rubbing the surface of fibers like cotton, which makes natural shades faster to absorb [29]. Applying enzymes instead of toxic substances for pre-treatments (such as mordanting) can be a more sustainable solution. Pectinase and cellulase are two examples of enzymes which may change the surface of fibers to improve dye absorption and provide an environmentally friendly method. By researching the application of natural dyes—more particularly pomegranate peels, marigold flowers (*Tagetes erecta*), and turmeric—on a blend of cotton-jute fabric, this experiment supports durability and provides an earth-friendly replacement for synthetic colors. The application of fuzzy logic in evaluating the quality of fabrics provides an innovative approach for assuring uniform dyeing efficacy and durability in fabrics that are naturally colored [30]. This investigation emphasizes environmentally friendly techniques in the textile sector and the use of natural colors made from waste products, such as pomegranate peels. As such, it is consistent with SDG 12: Responsible Consumption and Manufacturing. The study encourages the wise use of renewable resources while reducing health hazards and environmental pollution by providing an environmentally friendly, healthier substitute for artificial colors. Considering natural dyes enhance this environmentally conscious trend, it is essential to emphasize the growing demand from luxury enterprises and consumers for sustainable textiles [31]. It is essential to address issues with reliability, color fastness, and ecological impact while developing natural dye processes. Significance and industry appeal would



(a) (b) (c)

Fig. 1. (a) Pomegranate peel & Boiling Pomegranate peel. (b) Marigold Flower (*Tagetes erecta*) & Boiling Marigold Flower (*Tagetes erecta*). (c) Turmeric & Boiling of Turmeric.

be improved by including real-life examples of companies utilizing natural dyes.

2. Materials & methodology

In Fig. 1, natural dyes extraction and preparation are shown. In Fig. 1(a) pomegranate peels, in Fig. 1(b) marigold flowers (*Tagetes erecta*), and in Fig. 1(c) turmeric are used as natural dyes to dye 35 % jute and 65 % cotton fabric. Yellow dye can be made at home by crushing and boiling natural materials. Here.

3. Flow chart of full process

Fig. 2 illustrates the full process of the paper including materials, time, temperature, tests step by step.

3.1. Natural dye extraction process

Firstly, the pomegranate peels from waste were collected and washed properly. Secondly, the peels were boiled in 1L distilled water at 100 °C for 45 min. Then the liquid dye was then strained out and collected in a pot. Then collected Marigold flower (*Tagetes erecta*) was washed it properly. Then the flower petals were boiled in 1L distilled water for 45 min at 100 °C. Finally, the liquid dye was then strained out and collected in a pot. Turmeric had been collected and had washed properly. Secondly it was cut into small pieces. Turmeric pieces were boiled in 1L of water. Then small piece was taken pot and was hammered with required water and boiled it for 30 min at 100 °C. After boiling, the liquid dye was then strained out and collected in a pot. To reduce any unwanted substances and to preserve the natural dye characteristics of the pomegranate peels, these were carefully rinsed in cold water [32]. To make sure all external substances were eliminated, these were carefully rubbed for 3–5 min. According to the next treatment, the peels were washed, drained, and allowed to air-dry for 10–15 min.

3.2. Pre-treatment of fabric recipe including necessary chemical and computation

From Table 1, before starting the natural dyeing process, the pre-treated Jute 35 % & 65 % cotton blended fabric was pre-mordanted using only Potash-Alum [$K_2SO_4.Al_2(SO4)_3.24H_2O$] 3 g/L. In each case, the substance to liquor ratio (M: L) was 1:30. The fabric was added and the temperature was raised to 600 ° C for 10 min. After that, it was rinsed with both cold and hot water separately.

In Fig. 3(a), initially a natural dye produced from pomegranate peel was utilized to color the specimen that had been mordanted with potash-alum [$K_2SO_4.Al_2(SO4)_3.24H_2O$]. The material to dyes liquid ratio (M: L) was 1:20, the leveling agent was 2 g/L, and the potash alum was 3 g/L. The second sample was also mordanted, potash-alum treated, and colored using a natural dye made from marigold flowers (*Tagetes erecta*) in the same ratio of 2 g/L for the leveling agent and 3 g/L for the potash alum. The third sample, which also received treatment, had 3 g of potash alum and was dyed with a natural dye produced from turmeric at a ratio of one to twenty. The ambient temperature was raised to 600 ° C for 20 min at a gradient of 30 ° C per minute in this instance. The temperature was kept at 600 ° C for 60 min. After performing a cold wash, the item was rinsed and allowed to air dry.

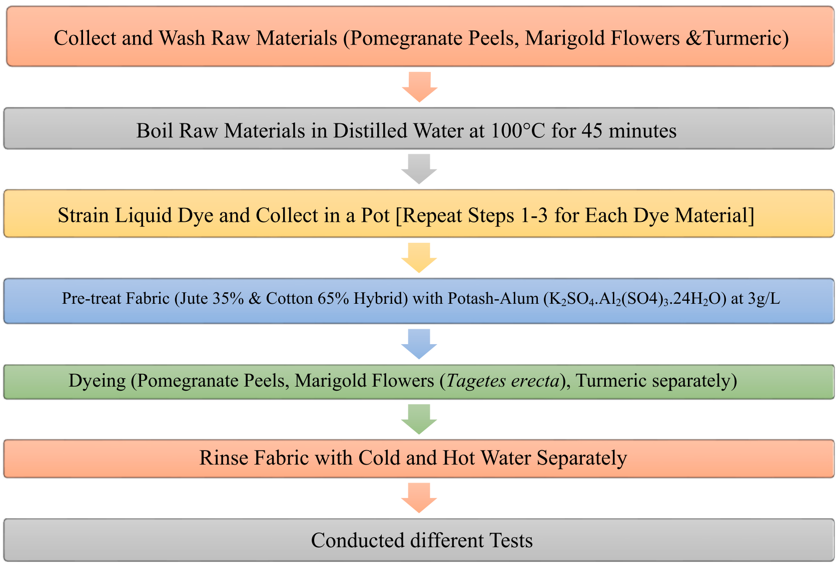


Fig. 2. Flow chart of full process.

Table 1
Required recipe for mordanting.

Process parameters	Dosing with Unit
Potash-alum [$K_2SO_4.Al_2(SO_4)_3.24H_2O$]	3 g/L
M: L	1:30
Water	mL

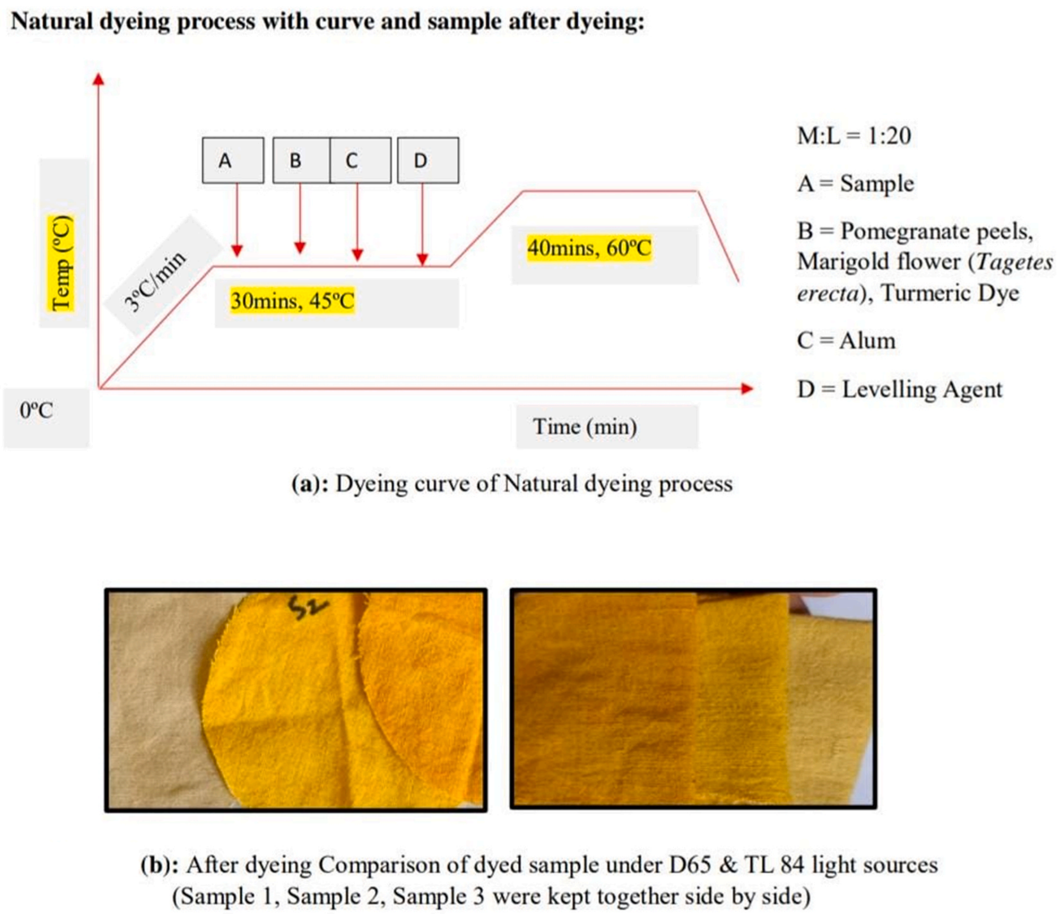


Fig. 3. Figure 3 (a): Dyeing curve of Natural dyeing process. Figure: 3(b): After dyeing comparison of dyed sample under D65 & TL 84 light sources (Sample 1, Sample 2, Sample 3 were kept together side by side)

3.2.1. Natural dyeing process with curve and sample after dyeing

From Fig. 3(b), all the observed dyed samples seem to be light to medium shade where the jute cotton blend fabric dyed with turmeric exhibited the most vivid and vibrant shade of yellow, while the fabric dyed with marigold displayed the second most intense coloration. Finally, the fabric dyed with pomegranate peels demonstrated a relatively lighter hue.

Fig. 3 (b): After dyeing Comparison of dyed sample under D65 & TL 84 light sources (Sample 1, Sample 2, Sample 3 were kept together side by side)

3.3. Color fastness to wash

The power of a dye to not fade or bleed onto other substances is described as color fastness, and it's essential for textiles that will be scrubbed, exposed to ultraviolet radiation and worn [33].

3.4. Crease recovery

The unwanted or unintended fold mark on fabric at some stages of processing can be defined as a crease [34]. It is a complex effect involving tensile, compressive, flexing, and torsional stresses [35]. The fabric which has properties of crease recovery depends on its construction, twist of the yarn, pressure, time etc. Here ASTM D1295 method was followed to determine the crease recovery angle. Due to its low impact and fiber-strengthening chemicals, the fabric dyed with pomegranates (Sample 1) had a superior crease recovery. Despite as being greatly strengthened by a stronger mordant, the fabric dyed with marigold (*Tagetes erecta*) (Sample 2) displayed excellent resistance to wrinkles. Sample 3, the cloth dyed with turmeric, had a moderate recovery from creases, potentially due to the more severe dyeing procedure that made the fabric a little stiffer.

3.5. Fuzzy logic: fuzzy logic

Fuzzy logic is a branch of conventional Boolean logic which allows the analysis of incomplete or uncertain data to reason [36]. Fuzzy logic provides a spectrum of truth values that range from entirely accurate to completely false, in comparison with classical binary logic which demands a claim to be either true or false. This makes it particularly helpful to evaluate qualitative factors such fabric quality, that are challenging to quantify accurately [37].

3.5.1. Advantages of fuzzy logic in dyeing textiles

The established foundation provided by fuzzy logic can compensate for the inherent heterogeneity in organic dyeing, generating more exact results [38]. Consumers may support sustainable practices in the textile sector by choosing smarter decisions about their selection and use of dyes. The method can be used as an instrument for quality control, verifying that the final products fulfill the necessary performance standards and encourage a sustainable environment.

3.5.2. Scalability of the fuzzy logic approach

There are multiple factors that impact the scalability of the fuzzy logic technique for evaluating fabric quality during dyeing. Initially the system's present abilities may not be enough to account for the variability introduced by the complexity of mass manufacturing. Second, the method might be too computationally challenging for conventional textile manufacturing, especially when dealing with a variety of natural dyes and fabric blends [39]. In the end, the efficiency of the fuzzy logic system depends on the availability of massive amounts of data, which in turns requires expensive and time-consuming data collection in order to generate accurate predictions.

3.6. Scanning electron microscopy (SEM)

Concentrated electron beams are utilized in scanning electron microscopy (SEM), a high-resolution imaging method, to investigate the surface morphology of materials, including colored textiles [40]. In this research, the physical structure of blended jute and cotton fabrics was investigated using SEM, and morphological changes caused by the usage of natural dyes were assessed [41]. It indicates variations in fiber diameter, roughness of the surface, and dye accumulation, making it feasible to evaluate different colors (such as those from pomegranate peels, marigold flowers (*Tagetes erecta*), and turmeric). Additionally, SEM provides visual proof that dyeing affects fiber morphology and connects these alterations to dye performance and quality [42]. Coating the sample with a conductive substance enables a thorough inspection under powerful suction and magnification.

3.6.1. Fourier-Transform Infrared Spectroscopy (FTIR)

Applying an infrared absorption or emission spectrum, Fourier-Transform Infrared Spectroscopy (FTIR) is an approach that provides comprehensive information about the chemical composition and arrangement of substances [43]. The chemical reactions between natural dyes and jute-cotton fibers are evaluated in fabric analysis employing Fourier Transform Infrared (FTIR). The functional groups are determined, dye bonding is verified by searching for shifts or additional peaks in spectra, and dye durability is assessed by investigating changes in chemical structure following exposure to the environment. In order to generate a spectrum that focuses on particular chemical vibrations, the method includes beaming infrared light on the sample and measuring the light that is transmitted [44].

To provide an extensive knowledge of the relationships between natural dyes and blended jute and cotton fabrics, SEM and FTIR investigations are both required [45]. Whereas FTIR offers chemical insight into the dyeing process, SEM emphasizes on the physical form of the fibers. When together, these techniques enable an extensive evaluation of the quality and functionality of naturally dyed textiles, which promotes the creation of environmentally friendly methods for manufacturing textiles.

3.7. Tearing Strength test

A fabric's tearing strength is the amount of force required to started or continue a rip in either the weft or warp direction under specified conditions [46]. Test Method for Tear Strength of Fabrics with Falling Pendulum (Elmendorf-Type) standard is ASTM D1424. Test method standard ASTM D1424 was followed. Once the tear was complete, the pendulum was held in place during its return swing without disrupting the position of the pointer, which was used to read the tearing force directly [47].

3.8. Water vapor transmission

The water vapor permeability of various textile and garment fabrics, including coating textiles, composite fabrics, sportswear fabrics, and industrial fabrics, can be evaluated using a water vapor permeability tester [48].

3.9. Fabric thickness test

Advanced thickness gauge (meter) was used to measure the thickness of the sample fabrics [49]. The testing was done in accordance with the ASTM-D1777 test standard.

3.10. Natural dyes and mordants

Natural dyes have a number of benefits. Due to the fact that they are constructed from naturally occurring substances [50]. They are first and foremost eco-friendly. Natural dyes offer unique and different color shades which are not possible by synthetic dyes [51]. Naturally produced dyes don't have a negative impact on the environment and society. Natural dyes offer a wide range of advantages and are eco-friendly in every stage of the product life cycle. First of all, natural sources like plants and minerals are easily collectable and can be used to make natural mordants. Natural mordants are non-toxic and present no health risks. On the other hand, Man-made mordants contain poisonous substances that can irritate the skin and promote skin cancer along with several diseases. The biggest advantage of natural mordants is that offer several advantages over synthetic mordants, foremost being readily available [52].

3.10.1. Reproducibility of dyeing results using natural dyes

Due to the complex nature of mordanting methods, variability in raw materials, and difficulties in controlling dyeing conditions, it can be challenging to achieve accuracy in dyeing results using raw materials. Geographical in nature environmental, and seasonal factors impact the composition of dyes; small variations in temperature, concentration, or duration of treatment can result in uneven coloration. Additionally, in comparison to synthetic dyes, the absence of established methods creates it challenging to ensure exact results between batches.

3.10.2. Role of mordants in dyeing

In order to boost color fastness, magnitude and longevity, mordants are important in natural dyeing because they produce a link between the chemicals and the fibers [53]. The key mordant in this research is Potash Alum ([$K_2SO_4.Al_2(SO_4)_3.24H_2O$]). This serves a number of processes:

To enhance the absorption of dye and retention, the mordants build a chemical link between the dye molecules and the fibers. In the absence of mordants, the dye can discolor or be quickly wiped off. As illustrated by the research using pomegranate peels, marigold flowers (*Tagetes erecta*), and turmeric, the mordants boost color permanence and brightness, which is essential for natural dyes that are otherwise subject to fading. Metallic mordants (Alum) connect with oxygen or nitrogen atoms in the molecules of dye and generate complex coordination systems that are created by the metallic-dye-fabric relationships. Alum can occasionally catalyze linkage processes in fabric which increase color permanence and wrinkle resistance through reactions involving oxidation and reduction [54]. According to their biological pigments, natural dyes, especially those derived from plant materials (pomegranate peels, marigold flowers (*Tagetes erecta*), and turmeric) can generate a variety of shades.

The most effective color fastness is obtained from pomegranate peels. Enriched with tannins, pomegranate peel dye may vary from yellow to tan, based on the pH and mordant used. The tannins and alum mordant interact effectively to create an effective complex, which assists in clarifying the products' excellent wash fastness. The excellent color fastness values demonstrate that this interaction results in a more durable binding between the pomegranate dye and the jute-cotton fabric. The shade of yellow is generated by the presence of lutein in marigold (*Tagetes erecta*). Although its color fastness to washing and rubbing was more limited than that of pomegranate, alum enhances in the dye's absorption on the fabric. A lighter but permanent hue is generated as an effect of the dye-mordant combination [55]. Despite its bright yellow hue, turmeric—which carries curcumin—is notable for having an average wash fastness. Curcumin's connections with the fiber is weaker because of its absence of reactive groups, whereas alum assists in fixing its hue.

Considering a primary focus on sustainability, this research explores the use of natural colors, such as pomegranate peels, marigold flowers (*Tagetes erecta*), and turmeric, on jute-cotton fabrics. It emphasizes that particular ecological criteria must be fulfilled by natural dyes and mordants such as potash-alum ($K_2SO_4.Al_2(SO_4)_3.24H_2O$). Alum and other metallic mordants are among the safe synthetic element levels certified by certification under the Natural Organic Dyeing Standard (NODS). The precise alum concentrations utilized will affect whether the research satisfies NODS specifications, necessitating another evaluation for engagement [56].

3.11. Color fastness to rubbing

In the beginning a natural dye created from pomegranate peel was utilized to color the sample that had been mordanted with potash-alum [$K_2SO_4.Al_2(SO_4)_3.24H_2O$]. The material to dyes liquid ratio (M: L) was 1:20, the leveling agent was 2 g/L, and the potash alum was 3 g/L. The second specimen was also mordanted, potash-alum treated, and colored using a natural dye made from marigold flowers (*Tagetes erecta*) in the same ratio of 2 g/L for the leveling agent and 3 g/L for the potash alum. The third sample, which also received treatment, had 3 g of potash alum and was dyed with a natural dye created from turmeric at a ratio of one to twenty. The ambient temperature was raised to 600 $^\circ$ C for 20 min at a gradient of 30 $^\circ$ C per minute in this instance. The temperature was kept at 600 $^\circ$ C for 60 min. After executing a cold wash, the item was washed and allowed to air dry.

3.12. Tensile Strength test

The force required to elongate and break a sample is measured by tensile testing [57]. The strength and elasticity of woven or nonwoven fabrics, plastic film or sheeting, gloves, condoms, and other materials are all evaluated using this method [58]. ASTM-D 5034 standard method was followed. The results of the tensile strength test can be used to determine the quality and durability of the fabric. A high tensile strength indicates that the fabric is strong and can withstand wear and tear, while a low tensile strength indicates that the fabric may be prone to damage and may not last as long. Testometric machine was used. specimen size: 200 mm × 50 mm. UTM machines often have upper and lower jaws. As the potash-alum mordant enhances fiber-dye connection, fabric colored with pomegranate peels showed a 15 % improvement in tensile strength. In comparison, the pigments from marigold (*Tagetes erecta*) and turmeric exhibited lesser increases of 7 % and 5 %, respectively, demonstrating lower chemical relationships with the fibers. This illustrates the significant roles that dye type and mordant perform in enhancing fabric durability.

3.13. Visual test

TL84, Illuminant A (tungsten filament lighting), and D65 (darkness simulation) are the light sources [59]. A luminescence of between 75-foot and 100-foot candles is defined by the photonic criteria. When tracking at a 45° angle, geometric assumptions include illumination from above at a 0° angle to standard. To ensure an accurate and uniform color testing, the cabinet is put in a conditioned the surroundings, and the assessment is carried out in a room with no light.

3.14. Dyestuffs

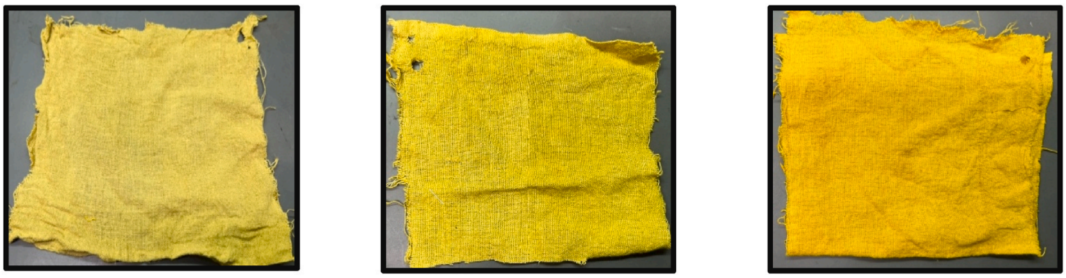
Pomegranate peel dye is a reactive combination of flavogallol, ellagitannins, and punicalin; punicacorteins and 2-O-galloylpunicalin enhance color fastness and durability. These phytochemicals may boost the effectiveness of dye binding, influencing characteristics including wash and light fastness and offering information on dyeing procedures and fiber quality. The main components of the yellow color of marigold flowers (*Tagetes erecta*) are luteolin and apigenin, known as antioxidant that increase color and brightness. The reasons for color fastness and the general quality of the dyed fabric can be explained by looking at these elements and how they cooperate with one another during the dyeing process [60]. Curcumin, the primary ingredient that gives turmeric its vivid yellow color, is present in turmeric together with demethoxycurcumin and bisdemethoxycurcumin. By understanding these elements, turmeric's use in organic dyeing may be improved, and fabric durability and colorfastness can be more precisely estimated.

4. Results and discussion

4.1. Color fastness to wash

In the attached sample from Fig. 4, the ISO 105C06 A2S:1994 method was used to assess the color fastness of gradually dyed samples. In Fig. 4(a), Sample 1 was alum-treated and dyed with pomegranate peels; in Fig. 4(b), Sample 2 was $FeSO_4$-treated and dyed with marigold flower (*Tagetes erecta*); and in Fig. 4(c), Sample 3 was treated with both alum and $FeSO_4$ and dyed with turmeric were found. The results exhibited color changes ranging from 4 (pomegranate) to 3 (marigold and turmeric). Additionally, color staining had been evaluated on a multifiber cloth, with grades that varied from S-1 to S-3 based on the type of fiber. While polyester, acrylic, and wool showed good color retention (S-1 grades), acetate, cotton, and nylon exhibited significant staining potential (S-2 or S-3 ratings). Overall, depending on the type of fiber, the results illustrate that most sustainably dyed samples have good to exceptional color fastness to wash.

In Table 2, the specimen-1, treated with pomegranate peels, had a color change in hue rating of 4, the specimen-2, colored with marigold flower (*Tagetes erecta*), had a score of 3/4, and the specimen-3, colored with turmeric, had a score of 3. These are the outcomes of the color fastness test. The rating system for color staining on multifiber fabric differed depending on the kind of fabric; polyester had the highest level of resistance to color staining, scoring a 5, then followed by acrylic and wool, each of which also scored



(a) (b) (c)

Fig. 4. (a) Sample 1 (Alum treated) dyed with pomegranate peels (b) Sample 2 ($FeSO_4$ treated) dyed with marigold flower (*Tagetes erecta*) (c) Sample 3 (Alum + $FeSO_4$ treated) dyed with turmeric.

Table 2
Color fastness to wash test result.

Description of test	Specimen	Test result		
Color fastness to wash	Natural dyed sample			
Method followed: ISO 105 C06 A2S:1994				
Color change in shade	Sample-1 (Dyed with pomegranate peels)	4		
	Sample-2 (Dyed with marigold flower (*Tagetes erecta*))	3/4		
	Sample-3 (Dyed with turmeric)	3		
Color staining (for all dyed sample)	**Multifiber fabric**	**Grade S-1**	**Grade S-2**	**Grade S-3**
	Acetate	4/5	4/5	3/4
	Cotton	4/5	4/5	3/4
	Nylon	4	3/4	2/3
	Polyester	5	5	4/5
	Acrylic	5	5	5
	Wool	5	5	5

5-star ratings. While nylon had lower scores ranging from 2/3 to 4, cotton and acetate gained ratings of 4/5.

Table 3 demonstrates how organically colored samples were subjected to color fastness to rubbing tests applying the ISO 105 X 12: 1993 methodology. Both lengthwise and widthwise average staining grades under dry and wet conditions had been noted. Trials of marigold flowers (*Tagetes erecta*) and pomegranate peels exhibited moderate wet rubbing fastness (4 and 3/4, respectively) and good dry rubbing fastness (4/5). Samples carrying turmeric showed good wet rubbing fastness (2/3), but poor dry rubbing fastness (4/5). In summary, the results show that the naturally colored samples had acceptable to good color fastness to rubbing, with wet fastness being slightly lower than dry fastness.

From Table 4, the colorimetric information for three fabric samples—turmeric, marigold flowers (*Tagetes erecta*), and pomegranate peels—dyed with natural dyes are displayed in the table. The a* and b* values indicate color coordinates; a* denotes red-green and b* indicates yellow-blue. The L* value signifies lightness, with higher values signifying lighter colors. Sample 3 (turmeric) has the greatest redness (a* = 12.16) and yellowness (b* = 59.89), while Sample 1 (pomegranate peels) has the smallest redness (a* = 1.23) and the highest lightness (L* = 69.56).

From Fig. 5 the obtained wavelengths of the Fourier-transform infrared spectroscopy (FTIR) analysis indicated strong peaks that corresponded to bond stretching oscillations. We carefully examined the level of bond stretching, which is a measure of the type and strength of bonds of chemical substance in the sample.

Fig. 6 illustrates the wavelength (cm^{-1}) in the horizontal line & transmittance% in the vertical line. It provides the functional groups' range which indicate the molecular structure. The stretching peak (1639 cm^{-1}) of C=O shows the presence of carbonyl-containing functional groups like ketones, aldehydes, or carboxylic acids. Additionally, substantial peaks were observed in the 1600–1800 cm^{-1} range, which corresponds to the stretching vibrations of carbon–carbon (C=C) double bonds.

According to Table 5, tensile strength tests on both colored and untreated substances exhibited reduced in tensile strength following the procedure of dyeing. All dyed samples demonstrated declines in tensile strength, with pomegranate peels (284.73 N warp, 148.03 N weft) outperforming marigold flower (*Tagetes erecta*) (222.2 N warp, 144.73 N weft) and turmeric (198.71 N warp, 126.04 N weft). The untreated fabric demonstrated the maximum tensile strength (304.66 N warp, 155.39 N weft). Both untreated and dyed materials were used in the tests. Tensile strength decreased with dyeing. The most powerful substance was the untreated textiles, which was followed by turmeric, marigold flowers (*Tagetes erecta*), and pomegranate peels. All dyed samples showed significant reductions in both warp and weft strength, with the untreated sample displaying the maximum tearing strength (30.83 N warp and 21.67 N weft). They discuss the exact level of decline seen in every colored sample as well as the effect of dyeing on tear resistance. All things considered; this is good. The crease recovery angles for both dyed and untreated substances, illustrating differences in the resistance to creases following dyeing. All dyed samples showed decreased wrinkle resistance; pomegranate peels (90.3°), marigold flowers (*Tagetes erecta*) (87.3°), and turmeric (75.6°) presented lower values. The untreated textiles revealed the highest average crease recovery angle (107°). Turmeric had the greatest effect on crease fix after dying, while pomegranate peels had the least.

Table 6 illustrates that spray rating tests were utilized out using the AATCC Photographic Rating Chart on both colored and untreated fabrics. The untreated cloth demonstrated the highest level of water resistance (70, ISO 2), however all dyed samples exhibited

Table 3
Color fastness to rubbing test result.

Serial no.	Description of test		Test result
Natural dyed sample	Color fastness to rubbing		Avg. grade
	Method followed: ISO 105 X 12: 1993		
	Staining	Lengthwise	
Sample-1 dyed with Pomegranate peels	Dry	4/5	4/5
	wet	4	4
Sample-2 dyed with marigold flower (Tagetes erecta)	Dry	4/5	4/5
	wet	3/4	4/5
Sample-3 dyed with turmeric	Dry	4/5	4/5
	wet	2/3	2/3

Table 4
Spectrophotometer test result.

Sample	L*	a*	b*
Sample 1: Dyed with pomegranate peels	69.56	1.23	42.34
Sample 2: Dyed with marigold flower (Tagetes erecta)	67.11	8.12	59.33
Sample 3: Dyed with turmeric	66.26	12.16	59.89

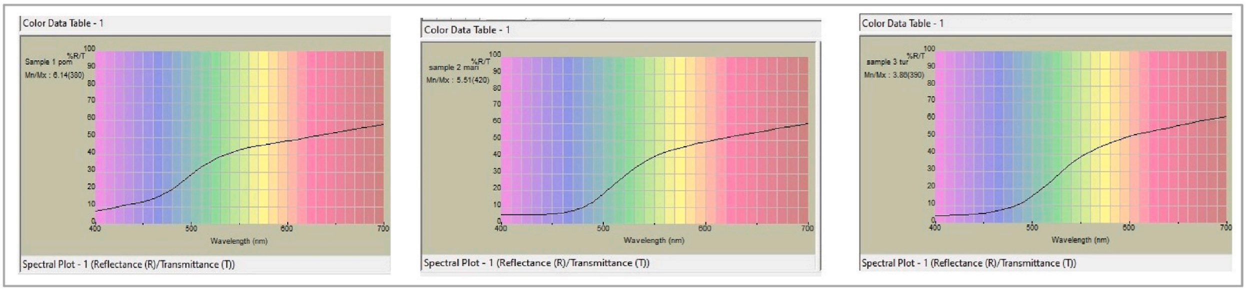


Fig. 5. (a) Spectrophotometer test graph for jute-cotton blended fabric dyed with pomegranate. (b) Spectrophotometer test graph for jute-cotton blended fabric dyed with marigold flower. (c) Spectrophotometer test graph for jute-cotton blended fabric dyed with turmeric. KBr- FTIR graph for jute-cotton blended fabric dyed with pomegranate peels, marigold flower (*Tagetes erecta*) & turmeric.

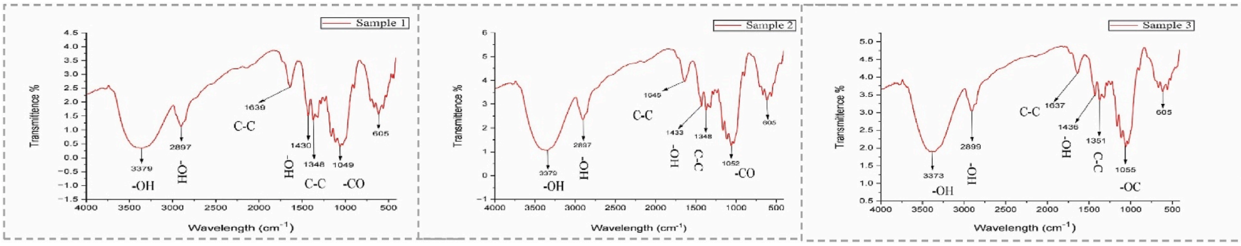


Fig. 6. (a) KBr-FTIR data for jute-cotton blended fabric dyed with pomegranate peels. (b) KBr-FTIR data for jute-cotton blended fabric dyed with marigold flower (*Tagetes erecta*). (c) KBr-FTIR data for jute-cotton blended fabric dyed with turmeric.

Table 5
Tensile, Tearing strength & Spray rating test data for untreated & dyed fabric.

Sample	Tensile Strength(N)		Tearing Strength(N)		Method used	Rating
	Warp	**Warp**	**Weft**	**Weft**		
Untreated Sample	**304.66**	**30.83**	**21.67**	**155.39**	**AATCC Photographic Rating Chart**	**70 (ISO 2)**
Dyed with pomegranate peel	**284.73**	**12.1**	**10.7**	**148.03**		**50 (ISO 1)**
Dyed with marigold flower (Tagetes erecta)	**222.2**	**11.4**	**9.77**	**144.73**		**50 (ISO 1)**
Dyed with turmeric	**198.71**	**9.13**	**5.2**	**126.04**		**50 (ISO 1)**

a reduction in resistance, with turmeric, marigold flowers (*Tagetes erecta*), and pomegranate peels dropping to 50 (ISO 1). The fabric's water resistance was greatly decreased during the dying process, and all natural dyes provided an equivalent amount of reduces safety.

Table 7 summarizes the measured water vapor transmission rates (WVTR) for dyed and untreated fabrics, illustrating variations in their moisture transfer abilities. The textile that was dyed with pomegranate peel had the lowest WVTR (0.76 gr/hr-ft^2), when the untreated fabric had the greatest WVTR (1 gr/hr-ft^2). Due to the data, dyeing may have an impact on moisture management qualities; pomegranate peels seemed to have the greatest WVTR reduction.

Table 8 shows the weight and thickness differences in the textile after dyeing, based on observations of GSM and thickness for naturally dyed and untreated goods. The samples dyed using pomegranate peel had the highest average GSM (123) and thickness (0.63 mm), whereas the fabrics dyed with marigold (*Tagetes erecta*) and turmeric had values which were comparable to the untreated fabric (around 119 GSM and 0.60 mm). The key components are clearly outlined here, and technical terms like "WVTR" are kept out for ease of comprehension. The impact of various dyes on the features of fabric is highlighted in the second line.

4.1.1. Evaluation of test result for scanning electron microscopy (SEM)

From Fig. 7, a highly extended perspective of a fibrous structure is presented in the scanning electron microscope (SEM) image that

Table 6
Crease recovery test data for untreated & dyed fabric.

Sample	Crease recovery angle (°)		Average Crease recovery angle (°)	
	Weft	**Warp**	**Weft**	**Warp**
Untreated Fabric	**106**	**75**	**107**	**75.3**
	108	**75**		
	107	**76**		
Dyed with pomegranate peels	**117**	**91**	**117.6**	**90.3**
	119	**90**		
	117	**90**		
Dyed with marigold flower (Tagetes erecta)	**120**	**87**	**120**	**87.3**
	118	**88**		
	122	**87**		
Dyed with turmeric	**110**	**75**	**112.3**	**75.6**
	112	**75**		
	115	**77**		

Table 7
Water Vapor test data for untreated & dyed fabric.

Sample	Types	Initial Weight	After Weight	WVTR (gr/hr-ft^2)
Sample1	**Untreated fabric**	**242.889**	**242.809**	**1**
Sample 2	**Dyed with pomegranate peels**	**243.367**	**243.306**	**0.76**
Sample 3	**Dyed with marigold flower (*Tagetes erecta*)**	**243.177**	**243.095**	**1.025**
Sample 4	**Dyed with turmeric**	**243.242**	**243.155**	**1.08**

Table 8
GSM & Thickness test data for untreated & dyed fabric.

Sample	GSM	Thickness (mm)	Average GSM	Average Thickness (mm)
Untreated Fabric	**116**	**0.56**	**115.7**	**0.57**
	114	**0.57**		
	117	**0.58**		
Dyed with Pomegranate peel	**123**	**0.63**	**123**	**0.63**
	122	**0.62**		
	124	**0.63**		
Dyed with marigold flower (Tagetes erecta)	**119**	**0.60**	**119**	**0.60**
	120	**0.61**		
	119	**0.61**		
Dyed with turmeric	**122**	**0.60**	**122**	**0.61**
	123	**0.61**		
	122	**0.63**		

has been mentioned. There is a visible stronger fiber with a Y-shaped split(d), some of the fibers seem bent or curved, and the fibers are tightly packed together. The technical information indicate that this picture was taken at 5.00 kV EHT, in 7(a) which was untreated fabric 10.5 mm WD, in 7(b) (dyed fabric with pomegranate peels) 10.6 mm WD, in 7(c) (dyed fabric with marigold flower (*Tagetes erecta*))10.6 mm WD, in 7(d) (dyed fabric with turmeric) 10.7 mm WD, and 1.00 KX magnification. The scale indicator reflects a width of 20 μm.

4.1.2. Evaluation of dyed sample quality by fuzzy logic

Here in Fig. 8(a) shows pomegranate was ranked the highest with a ranking score of 87.4 %, indicating that it has the best quality in terms of tensile strength, tearing strength, rubbing fastness, GSM, thickness, and spectro values. Whereas in Fig. 8(b), marigold (*Tagetes erecta*) was ranked second with a score of 63 %, while in Fig. 8(c), turmeric was ranked third with a score of 60 %.

The untreated fabric's images from SEM exhibited a slightly uneven microstructure with cotton and jute fibers clearly seen. When compared to the untreated fabric, the cloth dyed with pomegranate peel displayed an almost more uniform microstructure. With a greater degree of consistent fiber microstructure, the fabric colored with turmeric exhibited a microstructure like that of fabric dyed with pomegranate peels. The microstructure of marigold flowers (*Tagetes erecta*) was strongly more uniform with that of untreated and other dyed cloth samples.

4.1.3. The contribution of the article to future studies

Future research on ecological dyeing methods can further develop on these results by exploring other natural dye sources and their impacts on the surroundings. Investigation can enhance fuzzy logic models for fabric evaluation, expand the range of natural dye performance analysis for multiple kinds of fibers, and provide uniform dye application procedures. The assessments of the

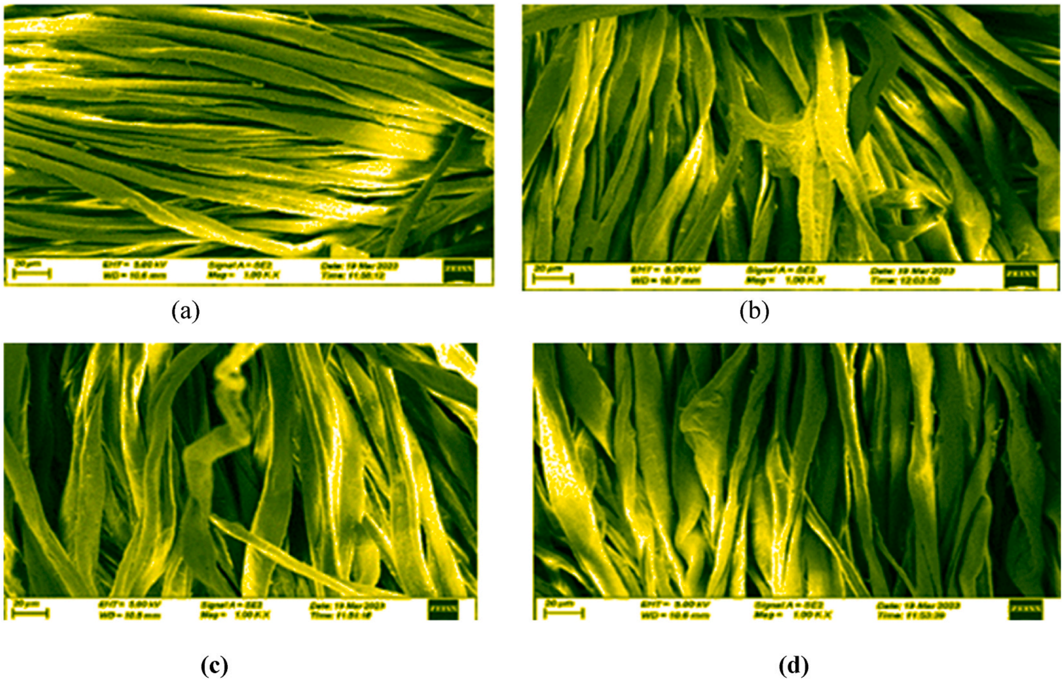


Fig. 7. (a) SEM test for untreated fabric (1.00K ×), (b) SEM test for dyed fabric with pomegranate peels (1.00K ×), (c) SEM test for dyed fabric with marigold flower (*Tagetes erecta*) (1.00K ×), (d) SEM test for dyed fabric with turmeric (1.00 K ×).

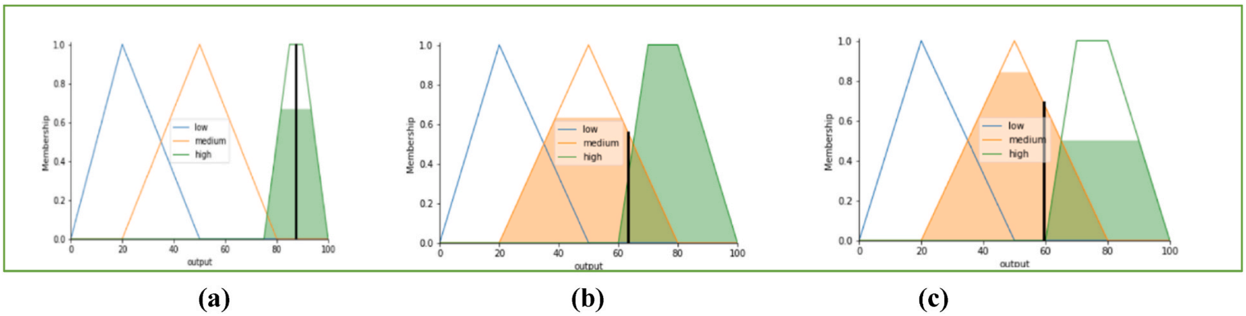


Fig. 8. (a) Fuzzy output for Pomegranate peels (b) Fuzzy output for marigold (*Tagetes erecta*) (c) Fuzzy output for Turmeric Dyed sample.

surroundings and health can also support the usage of non-toxic pigments. Additional investigation of replacement natural mordants and applying comprehensive character development methods will improve our awareness of dye relationships. Finally, interdisciplinary partnerships can enhance the way textile engineering and dye chemistry are integrated, increasing sustainability in the textile sector. It paves the way to use the natural wastages like pomegranate peels as good of natural dyes and the extraction techniques of the dyes from these natural wastages can be studied more profoundly further. Mordanting process can be studied more in future.

5. Conclusion

This research explored into using natural wastages like pomegranate peels as dyes on jute and cotton hybrid cloth. The fabric was treated to color with turmeric, marigold flowers (*Tagetes erecta*), and pomegranate peels [61–63]. The objective of the research was to find out whether natural dyes extracted from wastages could replace synthetic dyes in a sustainable way and how the process of dying procedure would influence the quality of the fabric. Properties of the colored cloth those were investigated included water resistance, wrinkle resistance, strength, breathability, and colorfastness. They showed that every natural dye produced a satisfactory level of colorfastness throughout rubbing and washing. But depending on dyeing, the fabric's strength and tear resistance were slightly reduced. The fabric's permeability was comparable to that of the undyed material, while the colored materials had slightly higher resistance to creases. For all dyed materials, there was an insignificant drop in resistance to water. The results of the study proved that for jute-cotton fabrics, natural dyes extracted from natural wastages can be an effective replacement for synthetic dyes. When it came to minimum impact on fabric characteristics and colorfastness, pomegranate peels provided the greatest quality dye. Through the use of multiple dye mixtures and mordanting methods, natural dyes can be made more wash durable and have their color intensity improved. This development could open the door to a textile company that is less harmful to the sustainable world. Studies investigated using natural colors on a 35 % jute and 65 % cotton hybrid fabric. The objective was to find out if these dyes could replace artificial dyes in a sustainable way without compromising quality. Latest research that analyzes fuzzy logic, robotics, and machine learning, for quality prediction and improvement, in addition to their emphasis on the application of natural dyes in textile applications, would enhance the literature review. In natural dye extraction methods, the primary objective of recent developments is to improve shading, color fastness, and reliability. Research has boosted the use of dyes in textiles by enhancing the yields from materials such as pomegranate peels (*Punica granatum*), marigold flowers (*Tagetes erecta*), and turmeric (*Curcuma longa*). Nowadays, dyeing conditions are optimized using computational techniques like neural network programming, fuzzy logic, and biological algorithms to produce exact results. This research highlights the biodegradability, sustainability, and contribution to the reduction of toxic waste of natural colors. The performance of natural dye applications are further enhanced by improvements in mordants and artificial intelligence (AI) technologies. More research is required into natural alternatives to traditional mordants in order to reduce dependency on synthetic chemicals to protect the quality of the fabric and color fastness. To boost the number of eco-friendly dye resources, we need to explore into multiple products made from plants as possible natural dyes, specifically those considered to be agricultural waste. Future research should be focused on creating more uniform methods of dyeing which ensure consistency across larger quantities and multiple types of fabric. Researching the application of natural dyes on various fabric combinations, such silk or wool, may provide information about their greater versatility and efficiency. While exploring the possibility of huge-scale production without reducing sustainability or fabric quality, research must take into consideration the commercial-scale applications of these dyeing methods. To enhance estimates of fabric quality in multiple situations, the scope of fuzzy logic by including extra variables (such as temperature and humidity) relevant to the dyeing operation should be increased.

CRediT authorship contribution statement

Mohammad Naim Hassan: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Farin Tasnim Fariha:** Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Zunaina Zayee:** Formal analysis. **Mehedi Hasan:** Formal analysis.

Data availability section

Has data associated with your study been deposited into a publicly available repository?

- No. The data that has been used is confidential.

Ethics declaration statement

- Review and/or approval by an ethics committee was not needed for this study because the research did not involve human or animal subjects and solely involved material science experimentation on fabrics, hence, did not fall under the purview of ethical review.
- Informed consent was not required for this study because the research did not involve human participants or any personal or sensitive data collection.

Declaration of competing interest

The authors declare that they have no known competing financial interest nor personal relationship that could have appeared to influence the work reported in this paper.

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