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Dyeing of Jute Fabric with Natural Colorants Extracted from Green Turmeric: A Green Approach of Jute Dyeing in Cottage Industry

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Abstract

Synthetic dyes conquered the natural colorants due to its outstanding properties of color matching, high clarities, better serviceability and ease of processing despite its adverse effect on environment. Jute fiber, the golden fiber of Bangladesh, is commercially dyed with hazardous synthetic dyes especially using basic dyes, which plays an adverse role on the environment. To overcome this issue, an attempt is made to apply an ecofriendly natural colorant extracted from green turmeric for the jute fabric to boost up the sustainable and cleaner wet processing of our golden fibre. In this study, the potentials of natural colorants extraction from green turmeric and consequent dyeing are evaluated. Natural colorants were extracted by facile boiling of green turmeric paste at 100°C for 60 minutes in aqueous, acidic and alkaline media. The solid residues were then separated from the solution with the nylon strainer. Subsequently, scoured and bleached jute fabrics were dyed with the extracted colorants in exhaust dyeing method. To investigate the effects of different synthetic mordants, mordanting of jute fabric were done with potash-alum, tannic acid, ferrous-(II) sulfate heptahydrate, stannous-(II) chloride pentahydrate, potassium dichromate, and copper-(II) sulfate pentahydrate. The impacts of temperature, dyebath pH, mordants, and dyeing period were intensively observed to get optimum dyeing conditions. The impact of dyeing parameters was evaluated in terms of color strength (k/s value) and chromaticity of the dyed fabric. The results revealed that different mordants, temperature, pH and dyeing period showed significant effects on the color strength and chromaticity. Potash-alum, tannic acid, and copper-(II) sulfate pentahydrate mordanted jute fabrics exhibited good color fastness to wash with a grey scale ratting of 3-4 to 4, while other showed poor color fastness to wash.

Keywords: *Jute Fiber, Natural Colorant, Green Turmeric, Mordants, Exhaust Dyeing.*

Introduction

From the time immemorial, the coloration of any article is a vital art and inseparable part as well of the human-civilization. The distinction of color in apparels is the replication of humans' imaginative mind which is sometimes regarded as the noble element in any society. However, indigo blue, the first organic colorant, was discovered nearly 4,000 years before on the mummy's wrappings in Egypt (Gupta and Suhas, 2009). Colorants from natural source, existed dominantly in the prehistoric human civilizations till the late 19th century (Hunger, 2007); that time colorants-extraction was just from natural sources. But with the marching of human-civilization to the industrialization, the synthetic colorants supersede the natural colorants (Holme, 2006). Nevertheless, the speedy industrialization and outstanding features of synthetic colorants: better serviceability, color matching, high clarities, ease of processing, and obtainability have finally conquered the natural colorants in the long run (Mani *et al.,* 2019).

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Nonetheless, because of the rising awareness about waste management and organic values of sustainable products, environment benevolent practice of dyeing (Mirjalili *et al.*, 2011) has attracted the ample attention including textile industries with the most noteworthy influence on the environmental pollutions (Haji *et al.,* 2020; Gorjanc *et al.,* 2018). It is projected that worldwide about 2,80,000 tons of textile dyes are discharged yearly as the industrial effluent (Liman *et al.,* 2020). But this large number of synthetic dyes is hard to counterbalance by the environment due to their non-biodegradability, and so persistent (Hassaan *et al.,* 2017; Manzoor and Sharma, 2020). Besides, these dyes have been demonstrated as health hazardous for both children and adults (Srivastava and Sofi, 2020). Hence, to address these issues, the international research attention transfers towards the natural colorants once again (Kumar and Sinha, 2010; Dawson, 2008; Shahid *et al.,* 2013). Additionally, in the recent past, various natural colorants obtained from diverse sources: microbes, animals, minerals, and plants are sustainable and renewable. These products are bio-resource based and have been studied for dyeing of textile and functional finishing process all over the world and a good number of works have already been done for the extraction of natural dyes from some easily available sources even in Bangladesh (Mamun *et al.,* 2022; Samanta and Agarwal, 2009; Samanta *et al.,* 2014; Islam *et al.,* 2022; Karim *et al.,* 2019; Liman *et al.,* 2021; Rahman Liman *et al.,* 2021). Though several researchers reported on the extraction process of dyes from different sources, even today, many of those remain unexplored. The possibility of turmeric has been explored in coloration of wool, silk, and cotton fabrics (Hosen *et al.,* 2021; Sarker *et al.,* 2020). But the uses of the green turmeric as a colorant for jute fabric coloration is known to be unexplored till date globally.

This study is an attempt to apply an eco-friendly natural colorant extracted from green turmeric for the jute fabric to boost up the sustainable and cleaner wet processing of our golden fibre. This research work intended to explore the possibilities of green turmeric through the experimental initiatives of (i) the extraction of natural dyes from green turmeric in various methods, (ii) the application and analyses of dyeing characteristics of jute fabric in the exhaust dyeing method and (iii) the study of the impacts of dyeing parameters on chromatic values and color strength of jute fabrics dyed with the extracted dyes.

Materials and Methods

Materials

Green turmeric was bought from village farmer of Santosh, Tangail, Bangladesh. Scoured-bleached jute fabric was purchased from regional supplier of Tangail, Bangladesh. Analytical grade sodium hydroxide, acetic acid, potassium dichromate ($K_2Cr_2O_7$), Potash Alum ($Al_2K_2(SO_4)_4$), Stannous (II) chloride pentahydrate ($SnCl_2.5H_2O$), Copper (II) sulfate pentahydrate ($CuSO_4.5H_2O$), Ferrous (II) sulfate heptahydrate ($FeSO_4.7H_2O$), and Tannic acid ($C_{76}H_{52}O_{46}$) were collected from Merck, Germany. ISO Standard reference detergent (without optical brightener) was collected from Dysin Chem Ltd., Dhaka, Bangladesh.

Dye extraction

The washed green turmeric (GT) was cut into small pieces. Then the small pieces of the GT were crushed in the kitchen blender to get fine paste. Later, GT paste (50 g/L) was boiled at 100^oC for 60 minutes using a pot of stainless-steel in aqueous, acidic and alkaline media. After that, the GT residue was separated from the solution with the nylon strainer. The process was repeated for extracting the required quantity of the dye solution. Finally, solution was used for the dyeing of jute fabrics in the exhaust dyeing method (Figure 1).

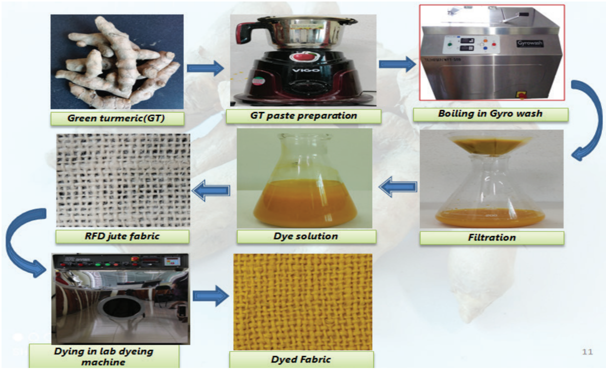

Figure 1. Pictorial flow chart for dyes extraction and dyeing

Typical process curve for dyeing of jute fabric

The dye bath was set with the required amount of dye solution and the fabric at 30^{o}C. Then, the temperature was raised at 100^{o}C at the rate of 3^{o}C per minute. At 100^{o}C temperature, process was continued for 60 minutes, then cooling and draining were done at 50^{o}C.

Typical process curve for aftertreatment of dyed jute fabric

For neutralization, the bath was set with the required amount of water and 2 g/L soda ash along with the dyed fabric at 30^{o}C. Later, the temperature was increased to 50^{o}C at the rate of 3^{o}C/minute. This was followed further for 10 minutes at that temperature, then cooling and draining was done at 40^{o}C. Soaping was done by setting the bath with the required water, and soaping agent 2 g/L along with dyed fabric at 30^{o}C. Later, the temperature was upgraded at 80^{o}C following the gradient of 3^{o}C/minute. This was continued further for 15 minutes at that temperature, then cooling and effluent-draining was done at 50^{o}C.

Typical method for temperature variation

To investigate the impact of temperature on the color strength and chromaticity five batches of jute fabrics (Each batch consists of 5 samples. Weight of each sample was 10 g) were dyed maintaining M: L of 1:20, dyebath pH 4- and 60-minutes dyeing time. Dyeing temperatures were 40°C, 60°C, 80°C, 100°C and 120°C.

Typical method for dyeing time variation

To investigate the impact of dyeing time on the color strength and chromaticity five batches of jute fabrics (Each batch consists of 5 samples. Weight of each sample was 10 g) were dyed maintaining M: L of 1:20, dyebath pH 4- and 100°C dyeing temperature. Dyeing period were 20 min, 40 min, 60 min, 80 min, 100 min and 120 min.

Typical method for pH variation

To investigate the impact of dyebath pH on the color strength and chromaticity five batches of jute fabrics (Each batch consists of 5 samples. Weight of each sample was 10 g) were dyed maintaining M: L of 1:20, dyeing time 60 min and 100°C dyeing temperature. Dyebath pH was adjusted to 3, 4,5 8 and 10 respectively. The acidic pH was adjusted using acetic acid while the alkaline pH was adjusted using soda ash as required.

Typical method for mordant variation

To investigate the impact of different mordants on the color strength and chromaticity five batches of jute fabrics (Each batch consists of 5 samples. Weight of each sample was 10 g) were dyed maintaining M: L of 1:20, dyeing time 60 min and 100°C dyeing temperature in presence of 5 g/l Potassium dichromate ($K_2Cr_2O_7$), Potash Alum ($Al_2K_2(SO_4)_4$), Stannous (II) chloride pentahydrate ($SnCl_2.5H_2O$), Copper (II) sulfate pentahydrate ($CuSO_4.5H_2O$), Ferrous (II) sulfate heptahydrate ($FeSO_4.7H_2O$), and Tannic acid ($C_{76}H_{52}O_{46}$) respectively.

Method for color strength and chromatic value measurement

Color strength and chromaticity of the dyed samples were measured with the help of spectrophotometer where illuminant was D65 and observer was at 10^{o}. Kubelka-Munk equation was deployed to measure K/S value (Eq. 1).

$$K/S = 1-R^2 / 2R \qquad (1)$$

where, R is the reflectance at any specific wavelength.

Method for determination of color fastness to wash of the dyed fabrics

The color fastness to wash of dyed fabrics was judged as per test method ISO 105 C06. A textile sample that comes into contact with a designated adjacent fabric or fabrics is cleaned, rinsed, and dried. In order to get the desired outcome in a reasonable amount of time, specimens are laundered under the proper temperature, alkalinity, bleaching, and abrasive action conditions. A low liquor ratio and the right amount of steel balls are used to achieve the abrasive action. Grey scales are used to evaluate the specimen's color shift and any staining of the nearby fabric or materials.

Results and Discussion

Extraction of natural colorants from GT was carried out in aqueous, acidic and alkaline media. Then the extracted colorants were applied on RFD jute fabric in exhaust dyeing method to dye the jute fabric samples. Dyeing was carried out by changing different dyeing parameters to optimize the parameters. Color strength and chromaticity of the dyed jute samples were evaluated using a data color. It is revealed that different dyeing parameters like temperature, dye bath pH, dyeing time, and various mordants affect jute dyeing using GT significantly and differently. Optimum dyeing temperature, dye bath pH, and dyeing time would be 60°C, 4, and 20 minute respectively. Potash-alum, tannic acid, and copper-(II) sulfate pentahydrate mordanted jute fabrics exhibited good color fastness to wash with a grey scale ratting of 3-4 to 4, while other showed poor color fastness to wash.

Impact of temp. in jute dyeing with GT extract

The impact of dyeing temperature on color strength and chromaticity and spectrophotometric images of dyed fabric is demonstrated in Figure 2. The relative measure of the amount of dyes in the dyed fabric is expressed by color strength K/S value. K/S is the ratio of amount light absorbed to that of the light scattered by a dyed material. Therefore, if K/S value is higher than amount of dyes in that material will be higher. The result illustrated that color strength increases as the increase of dyeing temperature up to 60°C. Color strength of the dyed samples was remained closer for dyeing temperatures of 80°C and 100°C. Color strength decreased significantly for the dyeing temperature of 120°. Generally, higher temperatures improve the color strength by enhancing the solubility of the dye and improving dye-fiber interactions (Burkinshaw 2024). However, there is a limit beyond which increasing the temperature might not yield proportional benefits. Too high temperatures may lead to degradation of the dye or the fiber, diminishing the overall color quality (Smoczyński *et al.,* 2020). Also, other studies (Gürses *et al.,* 2016; Chakraborty *et al.,* 2023) confirm that higher temperatures enhance dye uptake but also necessitates careful control to prevent adverse effects. On the contrary, chroma is a color property that shows how much a color deviates from grey of the same luminance. It might be understood to mean how colorful a thing is. A thing with a higher chroma is more colorful. The chromaticity of the dyed samples varied with the changes in dyebath temperatures. The impact of dyebath temperature on the chromaticity followed the almost similar trend to that of color strength of the dyed samples. The spectrophotometric images of the dyed fabrics also proved that lower dyeing temperatures produced more colorful samples and vice versa. Study indicates that different temperatures can affect the chemical structure of the dye, leading to variations in the hue, saturation, and lightness (Moula *et al.,* 2022).

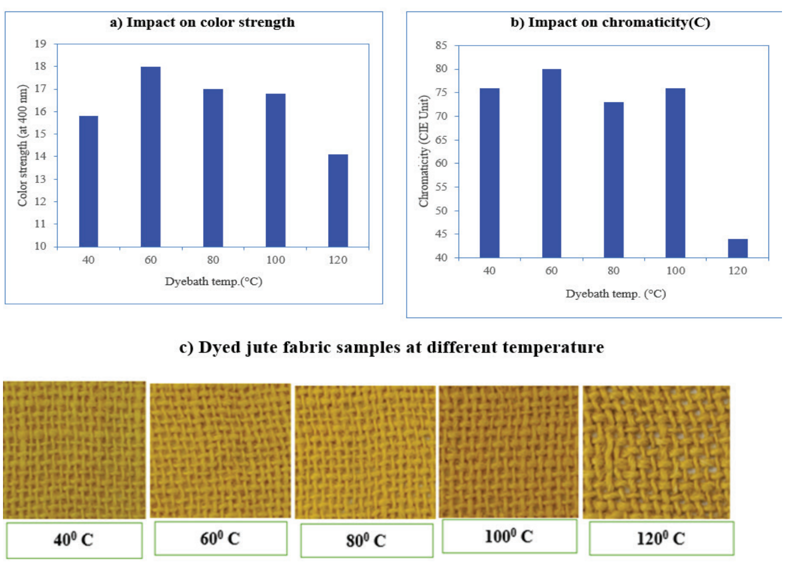

Figure 2. Impact of temperature in dyeing of jute fabric with green turmeric extract

For instance, a study (Chattopadhyay *et al.,* 2015) found that certain temperatures could cause shifts in the hue of turmeric dye due to its sensitivity to heat, and another study (Gürses *et al.,* 2016) showed that temperature optimization could enhance color saturation while maintaining desirable lightness levels in jute fabrics dyed with natural dyes.

Impact of dyebath pH in jute dyeing with GT extract

The impact of dyebath pH on color strength and chromaticity and spectrophotometric images of dyed fabric is demonstrated in Fig. 3. Dyebath pH influenced the color strength, chromaticity and spectrophotometric images of the dyed samples. Acidic dyebath found suitable for dyeing of jute fabric with green turmeric extract as both color strength and chromaticity values were observed higher in that case. The optimum dyebath pH was observed as 4 as the dyed sample exhibited higher color strength and chromaticity at this pH value. It was also noticed that alkaline dyebath is not suitable for dyeing of jute fabric with GT extracts. Color strength and chromaticity reduces considerably for higher pH values. Acidic conditions help in better fixation of the dye molecules onto the fiber. For turmeric, the presence of acidic conditions can enhance the solubility and stability of curcuminoids, leading to deeper and more intense colors (Mondal and Islam 2014). On the other hand, basic conditions during GT dyeing result in less vivid colors due to reduced dye uptake and less effective fixation (Chakraborty *et al.,* 2024). The spectrophotometric images of the dyed fabrics also proved that lower dyebath pH produced more colorful samples and vice versa.

Impact of dyeing period in jute dyeing with GT extract

The impact of dyebath pH on color strength and chromaticity and spectrophotometric images of dyed fabric is demonstrated in Fig. 4. It was observed that green turmeric extract had an excellent affinity to jute fabric as the dyeing equilibrium was achieved within very short dyeing time. The optimum dyeing period was found at 20 minutes both for color strength and chromaticity. It was seen that with the increase of dyeing period there was no further increase in color strength rather there was fluctuation.

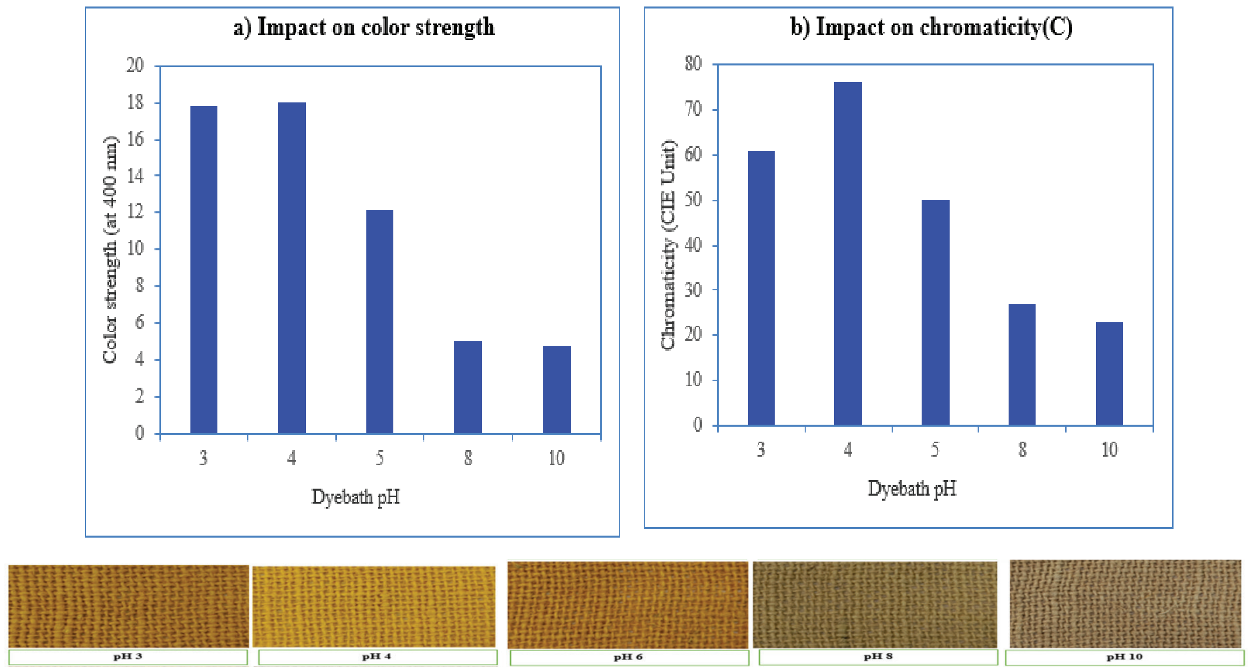

Figure 3. Impact of dyebath pH in dyeing of jute fabric with green turmeric extract

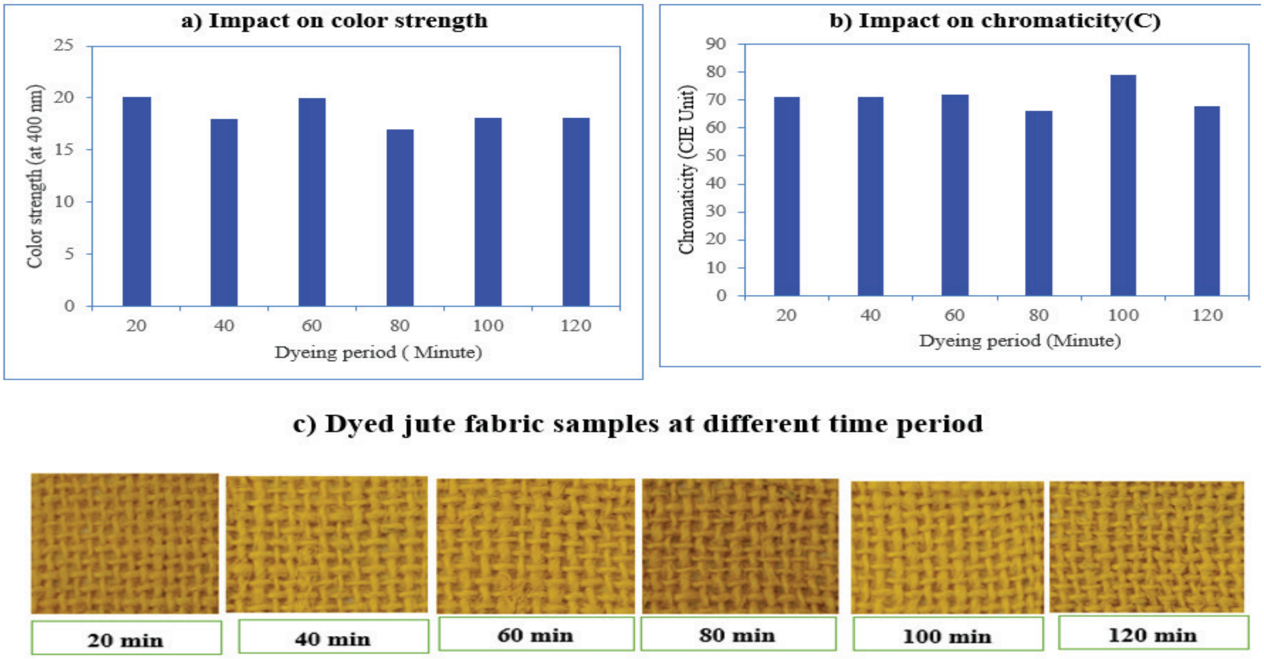

Figure 4. Impact of dyeing period in dyeing of jute fabric with green turmeric extract

In case of chromaticity, it was almost similar for 20 to 60 minutes dyeing period and then there was the maximum value of chromaticity at 100 minutes followed by a drop at 120 minutes dyeing period. Actually, increasing the dyeing time allows more dye molecules to penetrate and bond with the jute fibers, leading to deeper and more intense colors (Chakraborty and Pal, 2024). At the same time, excessively long dyeing times may not significantly improve color strength and can even lead to undesirable effects, such as overexposure causing uneven dyeing or potential fiber damage (Samanta *et al.,* 2012). The spectrophotometric images of the dyed samples also illustrated that dyeing period has lower impact in dyeing of jute fabric with GT extract.

Impact of different mordants in jute dyeing with GT extract

The impact of different mordants on color strength and chromaticity and spectrophotometric images of dyed fabric is demonstrated in Fig. 5.

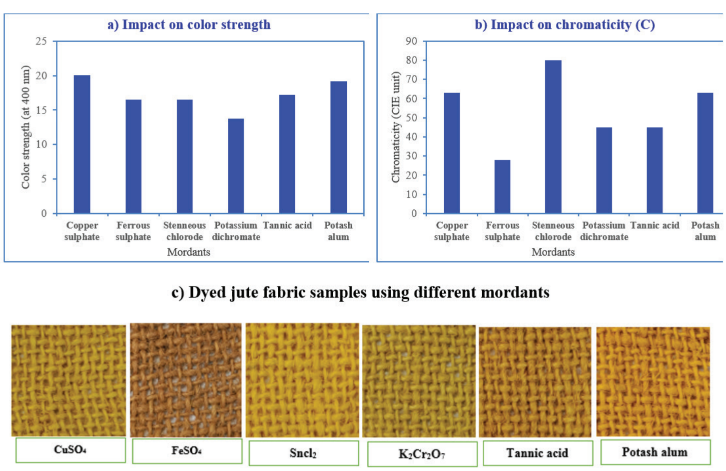

Figure 5. Impact of different mordants in dyeing of jute fabric with green turmeric extract

It was found that different mordanting agents had almost similar effect on the color strength but dissimilar effects on the chromaticity of the dyed fabrics. Comparatively higher color strength was observed for copper (II) sulfate pentahydrate ($CuSO_4.5H_2O$) and potash alum ($Al_2K_2(SO_4)_4$) mordants. Whereas ferrous (II) sulfate heptahydrate ($FeSO_4.7H_2O$), stannous (II) chloride pentahydrate ($SnCl_2.5H_2O$) and tannic acid ($C_{76}H_{52}O_{46}$) showed almost the same color strength. On the contrary, comparatively lower color strength was found for potassium dichromate ($K_2Cr_2O_7$) mordant. On the other hand, highest chromaticity was found for stannous chloride and lowest chromaticity was showed by ferrous sulfate. Potassium dichromate and tannic acid was found with equal chromaticity as well as potash alum and copper sulphate also showed same chromatic value. The spectrophotometric images of the dyed samples also illustrated that different mordants changed the appearance of the samples dissimilarly. Metal ions of different synthetic mordants act as a bridge between the dye and the fiber by forming complex bonds between them as illustrated in Fig. 5 and Fig. 6. The dye molecules bind to the metal ions, which then bind to the fiber (Canpolat *et. al.,* 2015). This helps in creating a more durable color. Copper (II) can produce a range of colors from greenish to bluish-green, due to the interaction between copper ions and curcuminoids in turmeric (Samanta *et al.*, 2012). Alum typically produces bright and light colors. It improves the natural yellow of turmeric, resulting in various shades of yellow **(**Rahman *et al.,* 2020**)**. The color is often less intense compared to other mordants, whereas ferrous sulfate often leads to darker and more subdued colors (Altay *et al.,* 2022). And when used with turmeric, it can produce brownish tones, as ferrous ions interact with the dye molecules to form insoluble dye-metal complexes. Stannous chloride usually produces deep, rich colors, and with turmeric, it intensifies the yellow shades and can provide more profound and robust hues as $SnCl_2$ forms strong complexes with dye molecules and jute fibers (Wanyama *et al.*, 2015). Tannic acid, a tannin-based mordant, forms stable complexes and results in a deeper and more intense color (Islam *et al.,* 2024). Potassium dichromate creates strong complexes with dye molecules, leading to bright and stable colors. It can sometimes make the fiber feel harsher due to its strong chemical interactions with the fiber (Samanta et al., 2012; Canpolat et. al., 2015).

Impact of different mordants on color fastness to wash for the dyed fabric

It was found that different mordanting agents had different impact on the color fastness to wash of the dyed fabrics.

Potash-alum, tannic acid, and copper (II) sulfate pentahydrate mordanted jute fabrics exhibit good to excellent color fastness to wash as the formation of strong complexes between the dye, mordant, and fiber helps in locking the color in place, making it more resistant to fading (Repon *et al.,* 2024; Rahman *et al.,* 2020); while the fabrics mordanted with other three mordanted fabrics exhibit poor color fastness to wash (Islam *et al.,* 2022).

Proposed mechanism

Fig. 5 shows the chemistry involved in the natural dyeing of cellulosic fiber with mordants in a complex structure. Metallic mordants act as a cross linker between cellulosic fiber and colorants. Curcumin, the main coloring components of turmeric, has the derivatives of dimethoxicurcumin and bis-dimethoxicurcumin (Canpolat *et al.,* 2015). The dyeing mechanism of jute fabric, curcumin, and potassium dichromate (metallic mordant) is shown below (Fig. 6).

Table 1. Impact of different mordants on color fastness to wash (Change in color) of GT dyed jute fabric

Fabric mordanted with	$Al_2K_2(SO_4)_4$	$CuSO_4.5H_2O$	$K_2Cr_2O_7$	$SnCl_2.5H_2O$	$FeSO_4.7H_2O$	$C_{76}H_{52}O_{46}$
Grey scale ratting (change in color)	3-4	4	2	2-3	2	4

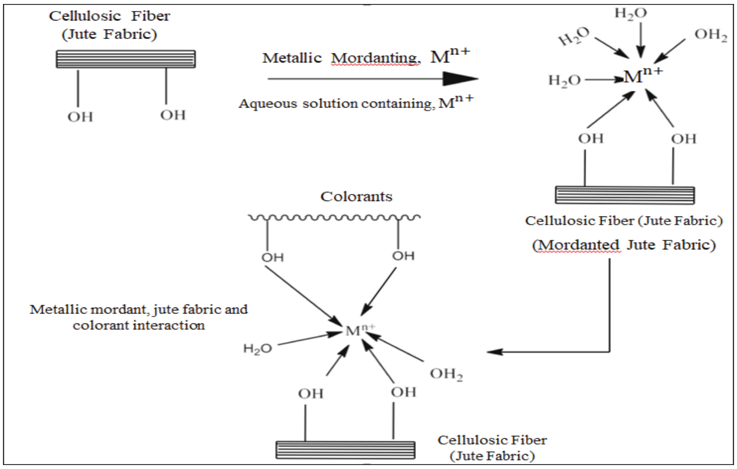

Figure 5. Proposed mechanism for interaction between metallic mordant, cellulosic fiber, and colorant (reproduced from Khan *et al., 2021)*

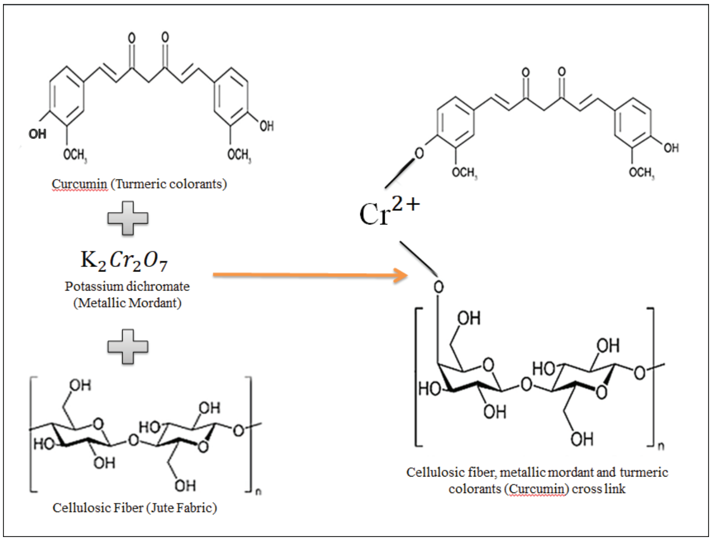

Figure 6. The dyeing mechanism of jute fabric with potassium dichromate and curcumin

Conclusions

Use of green turmeric as a source of natural colorant for jute dyeing is a new approach. Natural colorants got extracted from GT during boiling in alkaline, acidic and aqueous media. But the acidic GT extract exhibited best dyeing properties during dyeing of jute fabric. Dyeing parameters had profound impact on the properties of the dyed fabrics. Different hues can be produced with same dyes varying the mordants only. Dyeing of jute fabric with GT extract may open a new era in small cottage industries in producing various colorful crafts.

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Conflict of interest

Authors declared no conflict of interest.

Statement of author's credit

MAAM has role in supervision, review and editing, AIH has role in editing, data analysis, writing-draft manuscript and methodology, Julekha, TAH, BAL, SS has role in data collection.

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