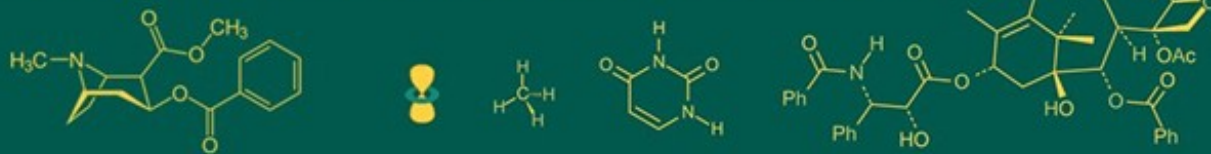


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Assessment of chitosan as an eco-friendly mordant for natural dyeing of cotton

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ABSTRACT

Growing environmental and health concerns associated with synthetic dyes have renewed interest in sustainable natural dyeing. However, the limited colour fastness of natural dyes on cotton necessitates the use of suitable mordants. The present study investigated chitosan as an eco-friendly mordant for cotton dyed with selected natural dyes. The optimum chitosan concentration was standardized based on colour characteristics and fastness properties, and its performance was compared with alum and ferrous sulphate. The treated fabrics were evaluated for colour fastness to sunlight, washing, rubbing and perspiration to assess the suitability of chitosan as a sustainable mordant for natural dyeing of cotton.

Keywords: Chitosan, Natural Dyes, Mordant, Eco-Friendly, Pollution, Synthetic Dyes

1. Introduction

India has a rich and long-established tradition of using natural colourants for textile coloration, with practices dating back to ancient times. Indian textiles were historically valued for their distinctive colours, aesthetic qualities and durability obtained through traditional dyeing techniques. The development of synthetic dyes in the nineteenth century, followed by their large-scale commercialization, resulted in a gradual decline in the use of natural dyes. Synthetic dyes became widely preferred because of their easy availability, convenient application, relatively low cost, reproducibility of shades and good colour fastness properties (Bhuiyan *et al.*, 2013) [1]. However, the release of dye-containing effluents and concerns associated with the toxicity, allergenicity and potential carcinogenicity of certain synthetic dyes have raised environmental and human health concerns (Siva, 2007; Affat, 2021) [3, 2]. Consequently, increasing awareness of sustainability and environmental protection has renewed interest in natural colourants and cleaner textile processing technologies. Recent research has therefore focused on exploring alternative natural dye sources and their application to textile substrates as potential substitutes for synthetic dyes (Periyasamy, 2020).

Natural dyes are obtained from diverse sources, including different parts of plants, animals and mineral materials. Their renewable origin, biodegradability and biocompatibility make them attractive for the development of more sustainable textile products (Alegbe *et al.*, 2024) [4]. Nevertheless, the wider application of natural dyes is constrained by several inherent limitations, such as low colour yield, variation in shade reproducibility, difficulties in standardization and inadequate resistance to washing and other external influences (Affat, 2021) [2]. In particular, many natural dyes possess limited affinity for textile fibres and are therefore unable to produce sufficiently durable shades without suitable pretreatment or mordanting. Mordants facilitate the interaction between dye molecules and textile fibres and can significantly influence colour development, depth of shade and colour fastness. Commonly used mordants include alum, ferrous sulphate, potassium dichromate, copper sulphate and stannous chloride (Kumar *et al.*, 2018) [5].

Although mordanting can improve the performance of natural dyes, the environmental compatibility of the mordant used is an important consideration in sustainable dyeing. Some conventional metallic mordants may introduce metal residues into wastewater and may therefore pose environmental concerns when improperly managed. Alum and ferrous sulphate are generally considered more suitable alternatives in comparison with certain chromium- and copper-based mordants. However, the search for safer and renewable mordanting agents remains important for the development of genuinely eco-conscious dyeing systems. In this context, considerable research attention has been directed towards mordants derived from biological materials and renewable resources, including plant-based materials and industrial or agricultural wastes (İşmal *et al.*, 2019) [6]. The use of such materials may reduce dependence on conventional metallic mordants while providing additional opportunities for developing sustainable textile processing methods.

Chitosan is a promising bio-based material for this purpose. It is obtained through the partial deacetylation of chitin, a naturally occurring nitrogen-containing polysaccharide found abundantly in various terrestrial and marine organisms and microorganisms (Shirvan *et al.*, 2019) [7]. The functional groups present in chitosan provide opportunities for interaction with textile fibres and colourant molecules, making it useful in

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several textile wet-processing and finishing applications (Zhou *et al.*, 2019) [8]. Previous studies have indicated that chitosan treatment can enhance dye uptake and colour strength on textile substrates (Elamri *et al.*, 2022) [9]. These characteristics, together with its biological origin and potential biodegradability, suggest that chitosan could serve as a suitable alternative to conventional mordants in natural dyeing. However, the effectiveness of chitosan may depend on its concentration, the type of natural dye and the nature of the textile substrate. Therefore, systematic evaluation of its mordanting performance in comparison with established eco-friendly mordants is necessary. With the growing interest in sustainable natural dyeing, the standardization of chitosan concentration as a mordant for selected natural dyes on cotton and its comparative performance with conventional eco-friendly mordants need to be studied. The relationship between chitosan treatment, dye absorption and the resulting colour fastness properties also requires further investigation to establish its practical suitability for cotton dyeing. Therefore, the present study was undertaken to standardize the concentration of chitosan as a mordant for selected natural dyes applied on cotton fabric. The study further aimed to evaluate the effect of chitosan mordanting on colour absorption, colour strength and colour fastness properties and to compare its performance with alum and ferrous sulphate. The findings are expected to provide information on the potential application of chitosan as a bio-based and environmentally preferable mordant for sustainable natural dyeing of cotton.

2. Materials and Methods

2.1 Selection of materials

- a. Dye materials: *Peltophorum pterocarpum* and *Rubia cordifolia*

- b. Yarn: Mercerised cotton yarn

- c. Mordants: Chitosan (75% deacetylated), alum and ferrous sulphate (FeSO₄)

- d. Chemicals: Acetic acid, Urea, Sodium bicarbonate and Sodium chloride of laboratory grade were used for colourfastness tests

2.2 Processing of chitosan

The required quantity of chitosan flakes was dissolved in a 2% (v/v) acetic acid solution at room temperature, and the resulting solution was used to mordant the cotton yarn.

2.3 Pretreatment of cotton yarn

To enhance dye absorption, the mercerized cotton yarn was boiled for 15–20 minutes and subsequently dried, following the procedure described by Michief (1992) [10]. The pre-treated yarn samples were then subjected to dyeing with the selected natural dyes.

2.4 Dye extraction parameters

The selected dye sources were extracted and applied under the dyeing conditions recommended by the AICRP on Home Science – Clothing and Textiles (Devi *et al.*, 2001) [11].

2.5 Mordanting procedures

Three different mordanting methods, namely pre-mordanting, simultaneous mordanting and post-mordanting, were employed for the treatment of cotton yarn.

Pre-mordanting: Prior to dyeing, the cotton yarn was treated with the mordant solution at 60 °C for 30 minutes. The treated yarn was subsequently used for dyeing with the selected natural dyes.

Table 1. Extraction and dyeing conditions of dye sources

Sources	Medium	Dye material concentration (gm/100 ml)	Alkali (gm/100 ml)	Extraction time (min)	Dyeing time (min)	Wave length (nm)
<i>Peltaphorum pterocarpum</i> (Bark)	Alkaline	7	1	60	45	440
<i>Rubia cardufolia</i> (Roots)	Aqueous	5	--	60	60	451

Simultaneous mordanting: The mordant and natural dye were applied simultaneously in the same dye bath and maintained for 30 minutes under the specified dyeing conditions.

Post-mordanting: Following dyeing, the cotton yarn was treated with the mordant solution at 60 °C for 30 minutes. The samples were then dried and evaluated for their colour characteristics and fastness properties.

2.5.1. Optimization of chitosan mordant concentration

The quantity of mordant required for treatment was determined with respect to the weight of the cotton yarn. Five concentrations of chitosan, ranging from 1 to 5% (owf), were initially evaluated for optimizing the mordant concentration. Among the three mordanting techniques, pre-mordanting was selected for optimization because it is a conventional and widely adopted method of mordant application. The mordanted yarn samples were subsequently dyed separately with each of the selected natural dye sources. To determine the extent of dye uptake, the absorbance of the dye liquor was measured using a spectrophotometer at the specific wavelength corresponding to each dye, both before and after the dyeing process. The percentage absorption

values, together with the visual assessment of the dyed samples, were considered for selecting the optimum concentration. Based on these observations, three concentration levels from the five tested concentrations were shortlisted for further evaluation using chitosan as the mordant.

As presented in Table 2, the dye uptake of cotton samples dyed with *Peltophorum pterocarpum* increased progressively with an increase in chitosan concentration. In contrast, cotton samples dyed with *Rubia cordifolia* exhibited a decreasing trend in dye absorption as the concentration of chitosan mordant increased. Although higher chitosan concentrations resulted in greater absorption values in some treatments, the corresponding dyed samples did not exhibit adequate depth of shade. Therefore, based on the combined assessment of dye absorption and visual depth of colour, chitosan concentrations of 1, 2 and 3% were selected for further dyeing experiments with both *Peltophorum pterocarpum* and *Rubia cordifolia*. For comparison with chitosan, the mordant concentrations adopted for alum were 5, 10 and 15%, while 1, 2 and 3% concentrations were used for ferrous sulphate, following the procedure reported by Devi (2001) [12].

Table 2. Optimization of chitosan mordant concentration for selected dyes

Dye	Mordant Concentration g/100gm yarn	Percent absorption
(continued on next page)		

<i>Peltophorum pterocarpum</i>	1*	29.8
	2*	39.6
	3*	40.5
	4	42.2
	5	38.3
<i>Rubia cordifolia</i>	1*	54.6
	2*	39.6
	3*	15.9
	4	12.3
	5	11.2

* Indicates the selected mordant concentrations

6. Dyeing

The chitosan-mordanted cotton samples were dyed separately with the selected natural dye sources, *Peltophorum pterocarpum* and *Rubia cordifolia*, following the optimized extraction and dyeing conditions presented in Table 1. The application of chitosan resulted predominantly in soft, lustrous and pastel shades on cotton. With *Peltophorum pterocarpum*, the chitosan-treated samples developed shades varying from creamish brown to moderate brown. Among the three mordanting techniques, pre-mordanting resulted in comparatively deeper shades with this dye. In the case of *Rubia cordifolia*, chitosan-mordanted cotton exhibited shades ranging from peach to pinkish brown depending on the mordanting technique, with post-mordanting producing relatively deeper shades.

A distinct variation in shade depth was observed when the chitosan treatment was compared with the conventional mordants, alum and ferrous sulphate. In general, the metal-mordanted samples produced darker shades than those treated with chitosan. Cotton dyed with *Peltophorum pterocarpum* developed light to moderate brown shades with alum and moderate to dark brown shades with ferrous sulphate. The *Rubia cordifolia*-dyed samples treated with alum exhibited shades ranging from pink to greyish brown, whereas ferrous sulphate produced predominantly pinkish-brown shades. For *Peltophorum pterocarpum*, pre-mordanting produced comparatively deeper shades when alum and ferrous sulphate were used. In contrast, the *Rubia cordifolia* samples showed better shade development with simultaneous and post-mordanting treatments.

The findings indicate that chitosan can be used to obtain softer and lighter pastel shades on cotton using the selected natural dyes. The difference in shade development may be attributed to the interaction between the dye molecules and the mordant under different mordanting conditions. Bechtold *et al.* (2003) [13] reported that the direct interaction of certain mordants with natural dye components during dyeing can promote complex formation and precipitation, which may influence dye availability in the dye bath. In the present study, no pronounced lake formation was visually observed in the chitosan-containing dye liquor. This may be associated with the nature of the interaction between chitosan and the dye molecules and the comparatively limited precipitation or aggregation of the dye-chitosan system. Similar observations regarding the interaction of chitosan with natural dye molecules have been reported by Rahman *et al.* (2024) [14]. Thus, the use of chitosan as a mordant may offer an alternative approach for developing soft, lustrous and pastel shades from natural dyes on cotton.

3. Results and Discussion

3.1 Evaluation of colour fastness properties of dyed cotton

The colour fastness properties of cotton fabrics samples dyed with *Peltophorum pterocarpum* and *Rubia cordifolia* using different mordants were evaluated by standard test methods. Colour change and

colour staining were assessed in accordance with the procedures specified in IS 768–1956 and IS 769–1956, respectively. The fastness ratings were determined using the grey scale, wherein a rating of 1 represents very poor fastness and 5 represents excellent fastness. Fastness to sunlight was evaluated using the Blue Wool standards prescribed by AATCC, with ratings ranging from 1, indicating very poor fastness, to 8, indicating outstanding fastness.

The dyed cotton samples were evaluated for colour fastness to sunlight, washing, rubbing and perspiration. The results indicated that the type of mordant had a noticeable influence on the fastness behaviour of the naturally dyed cotton fabrics.

The cotton samples mordanted with chitosan and dyed with *Peltophorum pterocarpum* and *Rubia cordifolia* exhibited good to excellent resistance to sunlight and rubbing. The washing fastness of the chitosan-treated samples ranged from fair to good, while satisfactory fastness was observed under perspiration conditions. These findings indicate that chitosan was effective in enhancing the interaction between the natural colourants and cotton fibres, thereby contributing to acceptable colour retention and resistance to colour transfer.

The samples treated with conventional mordants, namely alum and ferrous sulphate, also demonstrated good fastness properties. Excellent resistance to sunlight was observed in the fabrics mordanted with both alum and ferrous sulphate, while good fastness to washing, rubbing and perspiration was recorded. The comparatively higher fastness observed with these mordants may be attributed to the formation of relatively stable interactions between the mordant, natural colourant and cellulose substrate. Overall, the results demonstrate that mordant selection plays an important role in determining the fastness performance of naturally dyed cotton.

The comparative colour fastness results for cotton dyed with *Peltophorum pterocarpum* are presented in Figure 1. The chitosan-mordanted samples exhibited comparatively better resistance to colour staining during washing than the samples treated with the other mordants. The lower staining observed in the adjacent fabric suggests improved retention of the colourant within the cotton substrate following chitosan treatment. This behaviour may be associated with the film-forming and functional characteristics of chitosan, which can promote interaction between the colourant and the fibre surface and thereby reduce colourant migration during laundering.

However, the differences among the mordant treatments were relatively small for wet rubbing and perspiration fastness under both acidic and alkaline conditions. The comparable ratings indicate that mordant type had a limited influence on these particular fastness properties. The resistance observed under perspiration conditions may be related to the relatively stable association of the colourant with the fibre-mordant system.

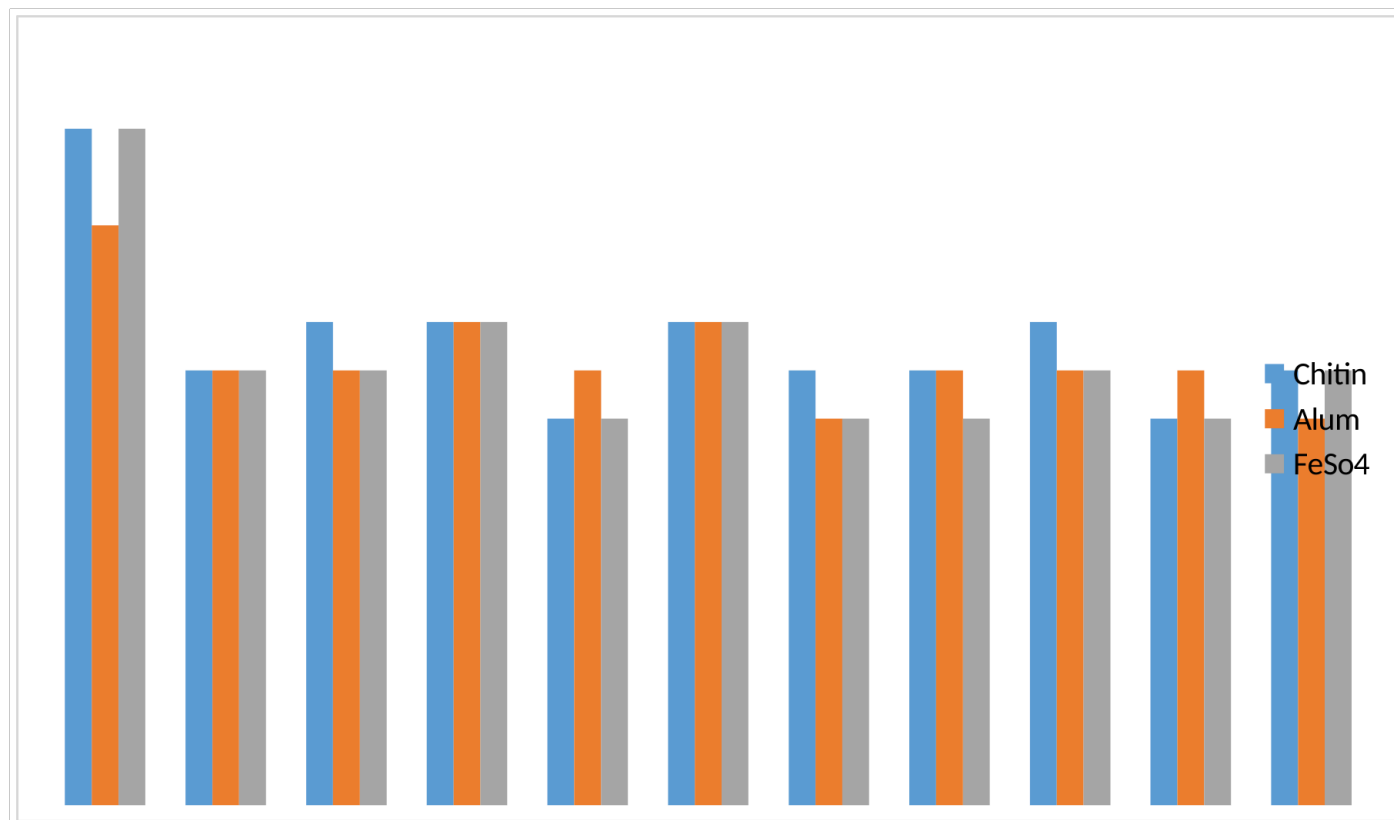


Figure 1. Effect of Chitosan, Alum and FeSO₄ mordants on *Peltaphorum pterocarpum* dye

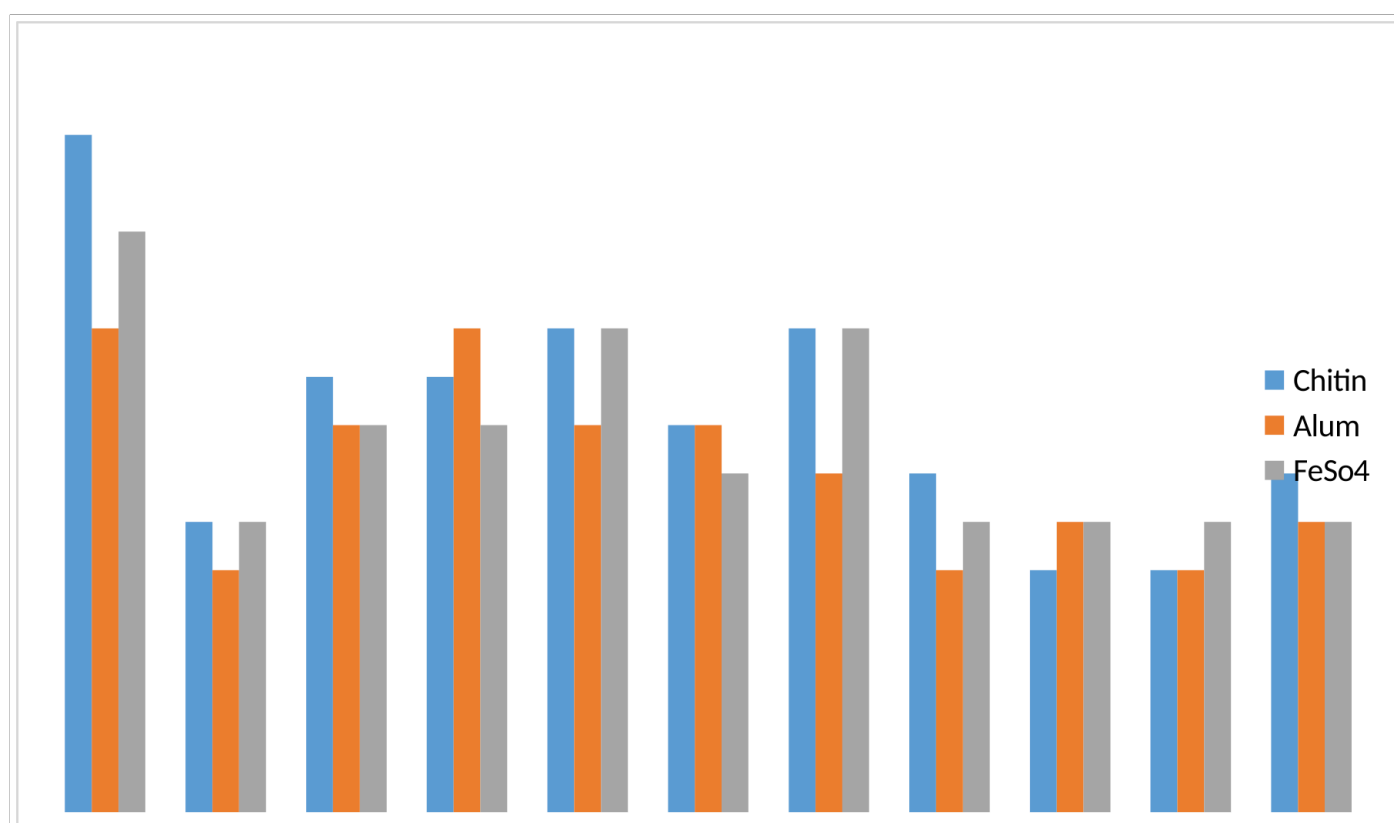


Figure 2. Effect of Chitosan, Alum and FeSO₄ mordants on *Rubia cordifolia* dye

As shown in Figure 2, the cotton samples dyed with *Rubia cordifolia* and mordanted with chitosan demonstrated good resistance to colour transfer during dry rubbing, with only slight staining observed on the adjacent fabric. The samples also exhibited satisfactory resistance under alkaline perspiration conditions. For the other evaluated fastness characteristics, the ratings of the chitosan-mordanted samples were comparable with those obtained for alum-mordanted samples. This indicates that chitosan was capable of providing an acceptable level of

colour fixation on cotton and, in several cases, produced fastness performance comparable to that of the conventional alum mordant. As presented in Figure 2, the chitosan-mordanted cotton dyed with *Rubia cordifolia* showed good resistance to colour transfer during dry rubbing, with only slight staining observed. The samples also exhibited satisfactory fastness under alkaline perspiration conditions. For the remaining colour fastness characteristics, the ratings of the chitosan-mordanted samples were comparable with those obtained for

the alum-mordanted samples. The comparable performance suggests that chitosan was able to provide an acceptable level of dye fixation on cotton without substantially compromising the fastness properties obtained with alum.

Differences in fastness behaviour between *Peltophorum pterocarpum* and *Rubia cordifolia* may be attributed to differences in the nature, chemical composition and affinity of their colouring constituents towards cellulose. The interaction of these colour-producing compounds with chitosan, alum and ferrous sulphate may also have contributed to the observed variation in colour retention and colour transfer. Thus, the findings suggest that chitosan has considerable potential as a bio-based mordant for improving the colour fastness properties of naturally dyed cotton, while providing a viable alternative to conventional metallic mordants.

4. Conclusion

The concentration of chitosan mordant was optimized at 1, 2 and 3% for cotton dyed with *Peltophorum pterocarpum* and *Rubia cordifolia*. The selection of the optimum concentration was based on the combined evaluation of dye absorption and the visual characteristics of the resulting shades. Chitosan treatment produced a range of soft, lustrous and pastel shades on the cotton substrate, with noticeable variations in shade depth depending on the dye source and mordanting conditions. The colour fastness performance of the chitosan-mordanted samples ranged from good to excellent under the serviceable conditions evaluated, including exposure to sunlight, washing, rubbing and perspiration.

Comparison with the conventional mordants indicated that both chitosan and alum were capable of producing attractive and relatively brighter shades with the selected natural dyes, although the depth and tone of colour varied according to the dye-mordant combination. The findings demonstrate that chitosan can improve the practical applicability of selected natural dyes on cotton while providing satisfactory colour fastness properties. Its ability to produce soft and lustrous pastel shades, together with its bio-based origin, makes chitosan a promising alternative to conventional mordants for natural dyeing. Thus, chitosan has potential as an environmentally preferable mordant for developing naturally dyed cotton textiles, particularly where softer and lighter shades are desired.

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