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Simultaneous Dyeing and Functional Finishing of Linen Fabric with Cinnamon Bark Extract Using Chitosan as a Mordant

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ABSTRACT

The resurgence of environmentally friendly products, such as natural dyes, is inevitable in the textile industry. Significant advantages can be achieved through combined dyeing and multifunctional finishing with natural dyes. In this study, linen fabric was dyed with aqueous cinnamon bark extract (CBE), using chitosan as an eco-friendly mordant. Initially, linen fabric was treated with chitosan solution using the pad-dry-cure method, and this chitosan-mordanted fabric was dyed using the exhaust method at different levels % on the weight of fabric (% o.w.f.). After dyeing, colour and functional properties of the dyed linen, including colour strength, fastness properties, antibacterial activity, antioxidant activity, UV protection, and mosquito repellency, were evaluated. The dyed linen with superior properties in terms of wash fastness (4-5), mosquito repellency (>90 %), good UV protection (UPF up to 25), antibacterial activity against E. Coli (upto 92.5 %) and moderate antioxidant activity (upto 66 %) was obtained. Additionally, treated linen fabrics showed good light fastness (3-4). Cinnamon bark extract (CBE) containing cinnamaldehyde and other phenolic compounds was confirmed as a dye and finish for linen fabric. The interaction between cinnamon biomolecules and chitosan was confirmed using UV-Visible spectroscopy and other analytical techniques. The structure-property relationship of dyed linen responsible for colouration and functional properties, were discussed. Prog Color Colorants Coat. 19 (2026), 401-415© Institute for Color Science and Technology.

1. Introduction

Nowadays, awareness of the need for sustainable manufacturing has underscored the importance of integrating green products and embracing sustainable manufacturing practices, given increased customer concerns, depleting resources, and increasingly stringent environmental policies [1]. The textile industry is one such industry which is reported to have very high effluent loads, causing environmental concerns worldwide [2]. Colouration of textile is a process which accounts for a substantially higher share of these effluents [3].

Hence, to address this need for change towards environment-friendly approach, various processes are being developed. Natural dyes are a sustainable solution in the textile business due to their environmentally friendly and therapeutic properties [4, 5]. They are easily biodegradable and possess exceptional functional characteristics, including antioxidant, antimicrobial, antifungal, and antiviral activities [6]. Apart from many benefits, limitations such as low colour yield, poor fastness ratings and non-reproducible shades pose challenges in the application of the natural dyes [7]. A mordant is substance that can attach itself to fibres and with the dyes [8]. The difficulty in dyeing of most non-

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substantive natural dyes necessitates the need to use metallic mordants, most of which are hazardous, polluting and pose a serious threat to the environment [9]. Hence, dyers are always in search of safe and effective natural mordants for the application of natural dyes [10].

Dyes with bioactive properties have already been synthesized and applied to various textile substrates, such as cotton, nylon, wool [11, 12] to impart functional properties during the stage of colouration itself which was conventionally being processed in separate finishing process. Approaches have been made to apply colour to textiles using simultaneous dyeing and finishing [13]. In the literature, dyes with antimicrobial, mosquito repellent and UV absorbent properties have been reported [14, 15]. Various natural dyes have already demonstrated to have significant bioactivity [16]. Even after mordanting, natural dyes have limited wash durability [7], which remains a major concern in terms of having longer life cycle of the naturally dyed fabrics.

Cinnamon bark is a source of various functional bioactive compounds that can be used for the simultaneous dyeing and finishing of textiles. Some important biomolecules of CBE are cinnamic acid, cinnamaldehyde and cinnamates.

Some studies on the use of cinnamon have already been reported. Wool was dyed using CBE without use of mordant [17]. In another work, wool was dyed with CBE using metallic and natural mordants such as date kernel, peppermint, banana peel, and Artemisia [18]. Cinnamon bark contains various amounts of phytochemicals, phenolic compounds with significant bioactivity, and vitamins [19], along with various natural compounds like cinnamates, which are known for their ability to absorb UV-B and UV-A radiations. These flavonoids exhibit antioxidant properties, whereas cinnamaldehyde showed mosquito-repellent activity [20]. Some researchers utilize cinnamon bark as a natural colourant for dyeing fabrics, especially natural fibres since it contains coloured biochemicals [21]. Quercetin and eugenol are two major phenolic components of the cinnamon bark [19]. Adeel and associates dyed silk and wool fibres using microwave-assisted extracts of cinnamon bark, concluding that the extracts have significant benefits [21]. Shahidi et al., examined the impact of saffron, cinnamon, and turmeric on the UV protection, transmittance, and antibacterial qualities of treated cotton textiles [22]. Kusstianti explored the application of cinnamon bark-based natural colorants for hair colouration [23].

Chitosan is an interesting polysaccharide which can act as a mordant in dyeing of textiles with natural dyes. Chitosan may interact with biomolecules present in cinnamon via ionic bonding, Schiff base interaction and Hydrogen Bonding. Chitosan is made up of β-(1→ 4)-2-acetamido-d-glucose and β-(1→ 4)-2-amino-d-glucose units. After cellulose, chitin is the second most bountiful bio-polysaccharide. Chitosan is produced by deacetylating chitin [24] to a degree of deacetylation (DD) of around 50 % [25]. Chitosan is biologically and chemically suitable for a variety of applications, including pharmaceutical and biomedical applications [26, 27], textile dyeing and finishing, fibre modification, wastewater treatment, paper production, and cosmetics [28, 29]. This is due to its high biocompatibility, biodegradability, and low cost [24]. It has also been used to prepare textiles resistant against biological agencies [30] and can serve as a bio-mordant in natural dyeing of textiles [31]. The protonated amino groups can form salt linkages with anionic dyes, resulting in strong interactions between the dye and chitosan, thereby imparting enhanced colour and better fastness properties [32]. Chitosan-treated cotton showed the highest UV protection compared to control (undyed) cotton fabrics [33]. The fabrics demonstrated good washing fastness in both dyed fabrics (chitosan-treated and fabrics not treated with chitosan); however, the light fastness rating is poor for fabrics dyed without chitosan pre-treatment [34]. Linen is a cellulose-based fibre with distinct features, derived from flax. The UV protection characteristics of linen fabric are determined by the degree of purification during the fibre processing [35]. However, due to its cellulosic nature, it is susceptible to assault by microorganisms and lacks antioxidant capacity [36]. Therefore, it is crucial to create a linen fabric that imparts antibacterial and antioxidant characteristics with the help of natural substances.

Although some research works dealing with the use of cinnamon bark in the dyeing of textiles have been reported, no studies have explored simultaneous dyeing and functional finishing of linen using chitosan as a mordant. The approach of using the cinnamon bark extracts (CBE) with chitosan bio-mordanting to achieve colour, antibacterial activity, mosquito repellency and UV protection on linen fabrics is unexplored. In this study, an attempt was made to explore simultaneous dyeing and functional finishing of linen fabric, as conventional dyeing and finishing are separate processes and consume more resources during application, including heat, water, electricity, manpower, and time. In this study, sustainability was targeted using natural dyeing, natural mordanting and combined processing. After dyeing, a detailed analysis of colour, fastness properties, and functional properties including anti-bacterial, antioxidant, UV protection, and mosquito repellency was performed.

2. Experimental

2.1. Materials

Linen fabric (Plain weave, ready for dyeing bleached, whiteness index: 60^+, Absorbency: less than one second, GSM 135, EPI 77, PPI 40) was purchased from the local market. Chitosan, citric acid, Sodium Hypophosphite were purchased from TCI chemicals. Cinnamon bark was obtained from the local organic store.

2.2. Methods

2.2.1. Preparation of chitosan solution and mordanting of linen fabric

A chitosan solution was prepared by dissolving chitosan (2 g) in an aqueous solution containing citric acid (5 g) and sodium hypophosphite (1.5 g) at 60 °C for 2 h using a mechanical stirrer. Linen fabric was treated with chitosan solution using the Pad (70% expression)-Dry (80 °C for 5 min)-Cure (170 °C for 1 min) method.

2.2.2. Preparation of dye extract from cinnamon bark and dyeing of mordanted linen

5 g of cinnamon bark powder was suspended in 100 mL D.I. water and heated for 1 h at 90 °C using magnetic stirrer at 300 rpm. The resultant extract was cooled to room temperature, filtered through filter paper, and used for dyeing as 5 % w/v stock solution. A UV-Visible spectrophotometer (Shimadzu Corp 81464, Japan) was to used analyze the absorption pattern of the aqueous extract. The mordanted linen was dyed using CBE at different shades (10, 20, 30, 50 and 100 % o.w.f.) with MLR 1:20 using exhaust method at 60 °C for 1 hr. Throughout the dyeing, the pH of the solution was in the range of 5-6 which was confirmed using pH paper. After dyeing, fabric was rinsed with tap water and dried using air drying method.

2.2.3. GC-MS analysis of the methanolic extract of cinnamon bark

A methanolic extract of Cinnamon Bark powder (1 % w/v) was prepared by adding 0.25 g of cinnamon bark powder in 25 mL of ethanol. The mixture was then stirred at 50 °C under reflux conditions for the duration of 120 min. The mixture was allowed to cool down to room temperature. Its phytochemical composition was analysed using an Agilent Technologies-8890 GC system coupled to an Agilent Technologies-5977B GC/MSD mass spectrometer. Spectra and chromatograms were processed using Mass Hunter GC-MS software.

2.2.4. UV visible spectrometry

A UV-Visible spectrophotometer (Shimadzu Corp 81464, Japan) was employed to compare the absorption patterns of virgin cinnamon extract (CBE), chitosan solution, and combined extracts, and to confirm the formation of coloured compounds by identifying changes in maximum wavelength (λ_{max}) of the solutions.

2.2.5. Characterization of dyed fabrics

FTIR was used to analyze the functional groups in control (undyed) and dyed linen fabrics. Thermogravimetric analysis was used to characterize the thermal stability of fabrics in the temperature range of 50-600 °C.

2.2.6. Colour measurement

Colour strength (K/S) and colour values were obtained using CCM (computer colour matching) system. The dyed fabric was evaluated for colour fastness to washing as per ISO-105-C06-A1M:2010 standard. Rubbing fastness was assessed according to ISO105-X12:2016 standard. Light fastness was assessed according to ISO 105- B02:2006 standard [37].

2.2.7. Functional properties

Using female *Anopheles* mosquitoes, the Arm-in-Cage technique was used [33] to evaluate the mosquito-repellent properties of coloured linen fabric. For the investigation, a cage full of mosquitoes was used. After being wrapped in both dyed and control (undyed) linen fabrics, the volunteer's arm was placed inside the cage.

The mosquito-repellency of dyed linen fabric was calculated using the following formula (Eq. 1):

$$\text{Mosquito repellency (\%)} = [\frac{(U-D)}{U} \times 100] \quad (1)$$

where, U is the number of mosquitoes that land on control (undyed) fabric and D is the number of mosquitoes that land on coloured fabric.

Using the AATCC-100 standard, the antibacterial activity of dyed linen samples was assessed [38]. Using the following formula (Eq. 2), the number of colonies on the petri plate was counted to determine the antibacterial activity.

$$R = [\frac{(A-B)}{A}] \times 100 \quad (2)$$

Here, A is the number of bacteria recovered from the inoculated dyed fabric specimen swatches in the jar immediately after inoculation at zero contact time, B is the number of bacteria recovered from the inoculated dyed linen swatches in the jar incubated for 24 hr., and R is the percentage of bacterial colony reduction.

UV protection of samples was measured according to AS/ NZS 4399-2017 [39]. The following formula (Eq. 3) was used to determine the UV protection factor (UPF) value.

$$UPF = (\sum_{280}^{400} E \times S \times \Delta\lambda) \div (\sum_{280}^{400} E \times S \times T \times \Delta\lambda) \quad (3)$$

where, E represents relative erythemal spectral effectiveness, S = spectral irradiation of the skin in UV region, T = spectral transmittance of the fabric, λ = wavelength (nm), Δλ = an increment relating to wavelength.

The antioxidant characteristics of the dyed fabrics were analyzed by assessing their radical scavenging activity against the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) radical at 517 nm [15] after 30 min contact with control and the dyed samples (Eq. 4).

$$\text{Antioxidant activity (\%)} = [\frac{(A-B)}{A}] \times 100 \quad (4)$$

where A represents absorbance of the DPPH solution in contact with the Control sample and B refers to absorbance of the DPPH solution in contact with the dyed linen sample.

2.2.8. Durability of mosquito repellency

To evaluate the durability of the mosquito repellent property, the dyed fabrics were washed according to ISO 105- CO6-A1M test methods [37], and the washed fabrics were re-evaluated for their mosquito repellency as per arm-in-cage method.

3. Results and Discussion

3.1. Characterization of cinnamon bark extract

Figure 1 illustrates count v/s acquisition time in mins of the 1 % w/v methanolic extract of virgin cinnamon bark powder. Some of the compounds identified in the GC-MS analysis are listed below in Table 1. GC-MS analysis confirmed the presence of cinnamaldehyde along-with other aromatic compounds.

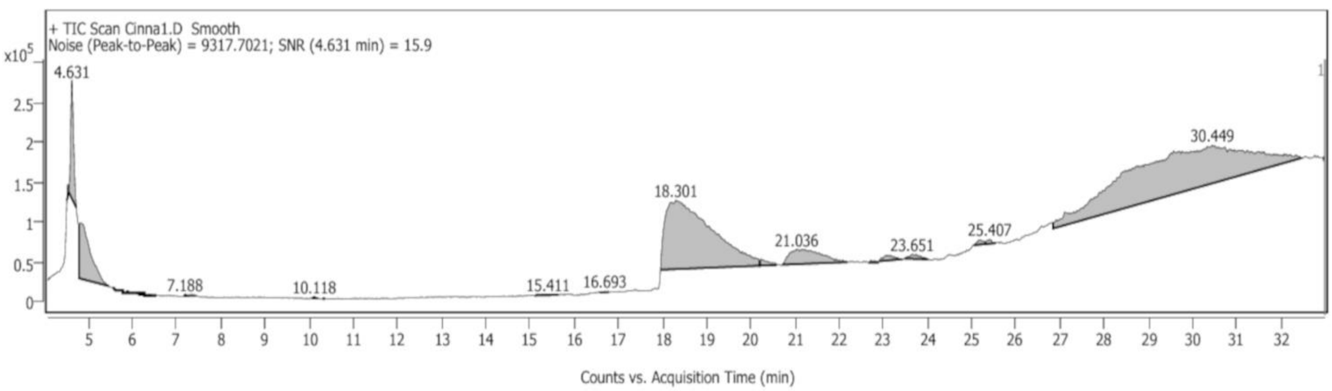


Figure 1: Count v/s acquisition time in minutes.

Table 1: GC-MS analysis of methanolic extract of cinnamon bark

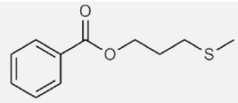
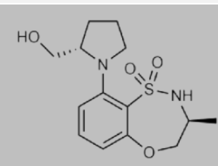
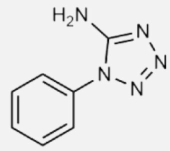
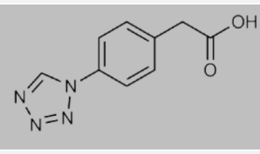
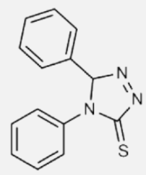
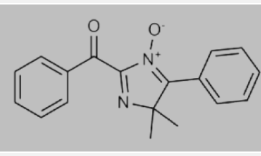
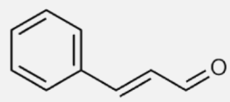
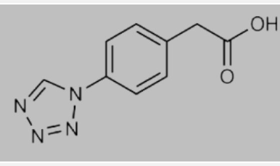
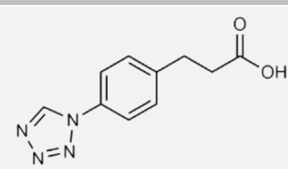
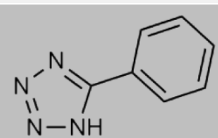
Peak No.	RT	Chemical Name	Mol Wt.	CAS No.	Area %	Chemical Structure
1	4.825	3-(Methylthio)propyl benzoate	210.29	1000367-09-7	14.35	
2	10.118	(S)-9-[(S)-2-(Hydroxymethyl)pyrrolidin-1-yl]-3-methyl-3,4-dihydro-2H-benzo[b][1,4,5]oxathiazepine 1,1-dioxide	312.38	1334427-13-2	0.10	
3	10.336	1-Phenyl-1H-tetrazol-5-amine	161.16	5467-78-7	0.02	
4	15.411	Benzoic acid 1-methoxy-1H-tetrazol-5-ylmethyl ester	234.21	1000296-08-2	0.20	
5	15.554	3H-1,2,4-triazole-3-thione, 4,5-dihydro-4,5-diphenyl-	253.32	1000396-68-6	0.04	
6	16.693	2-Benzoyl-4,4-dimethyl-5-phenyl-4H-1,3-diazol-1-ium-1-olate	292.33	107946-03-2	0.08	
7	18.301	Cinnamaldehyde, (E)-	132.16	14371-10-9	73.08	
8	20.235	Benzene acetic acid, 4-(1H-1,2,3,4-tetrazol-1-yl)-	204.19	1000351-56-5	1.20	
9	21.036	Benzenepropanoic acid, 4-(1H-1,2,3,4-tetrazol-1-yl)-	218.21	1000349-98-4	10.67	
10	22.724	1H-Tetrazole, 5-phenyl-	C7H6 N4	18039-42-4	0.27	

Figure 2 shows UV Visible spectra of CBE (1 %) and the interaction product of chitosan and CBE in citric acid. There is slight shift in maximum absorbance wavelength (λ_{max}) from 285 (cinnamon) to 279 (Chitosan + cinnamon dye) in UV region. This shift in λ_{max} confirms the interaction between cinnamon biomolecules with chitosan.

3.2. Proposed mechanism of simultaneous dyeing and finishing of linen

The proposed mechanisms for simultaneous dyeing and finishing reactions are presented in Figures 3-5. Citric acid reacts with primary hydroxyl group of cellulose and free amino group of chitosan, forming cellulose cross-linked with chitosan at 170 °C for 1 min during curing stage as shown in Figure 3.

This chitosan-treated linen, when subjected to exhaust dyeing treatment with aqueous cinnamon bark extract, forms covalently bound cellulose-chitosan-cinnamaldehyde in the presence of acidic conditions forming Schiff's base (demonstrated in Figure 4), resulting in the wash-durable antimicrobial, UV resistant, antioxidant and mosquito repellent linen fabric. The acidic conditions required for the reaction might be facilitated by the presence carboxylic acid groups from citric acid and cinnamic acid.

The primary amino group of chitosan is protonated at acidic pH and functions in two ways for fixation of the phenolic groups. Firstly, it forms hydrogen bonds with OH groups of phenolic components Quercetin and Eugenol (as demonstrated in Figure 5a). Acidic pH helps increase the solubility of the chitosan amino group through protonation, making it easier for H-bond formation than unprotonated chitosan. This increases the number of hydrogen bonds formed between phenolic groups and cellulose cross-linked chitosan, thereby enhancing hydrogen bond formation, and fixation of the colour-imparting phenolic groups [40].

And secondly, the protonated primary amino group interacts with deprotonated carboxylic acid group of phenolic acids, forming salt linkages between cellulose cross-linked chitosan and deprotonated phenolic acid (demonstrated in Figure 5b).

3.3. Colour strength of dyed linen

The colour strength was measured using CCM (computer colour matching), and the results are summarized in Table 2.

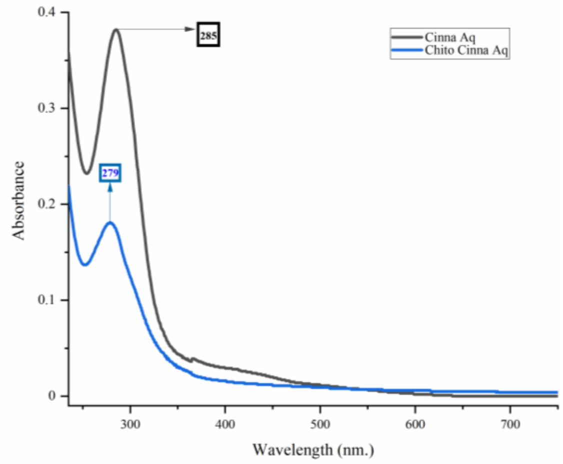


Figure 2: UV-Visible absorption spectra of cinnamon (1 %) aqueous extract and the complex of chitosan and cinnamon biomolecules.

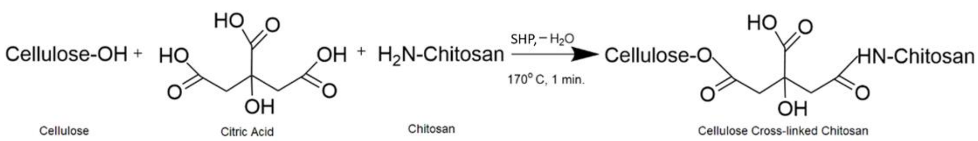


Figure 3: Crosslinking of chitosan with cellulose through citric acid.

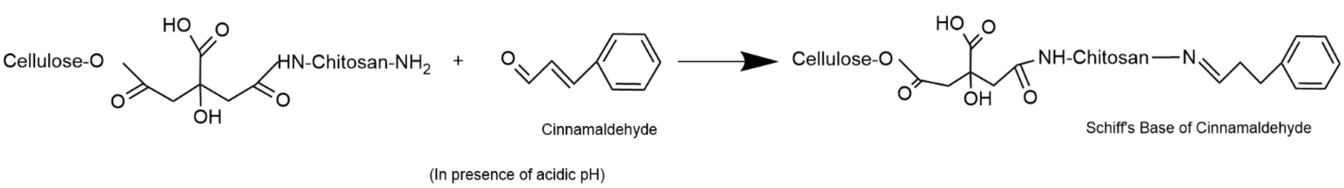


Figure 4: Possible reaction mechanism of Schiff's Base formation of cellulose cross-linked chitosan with cinnamaldehyde.

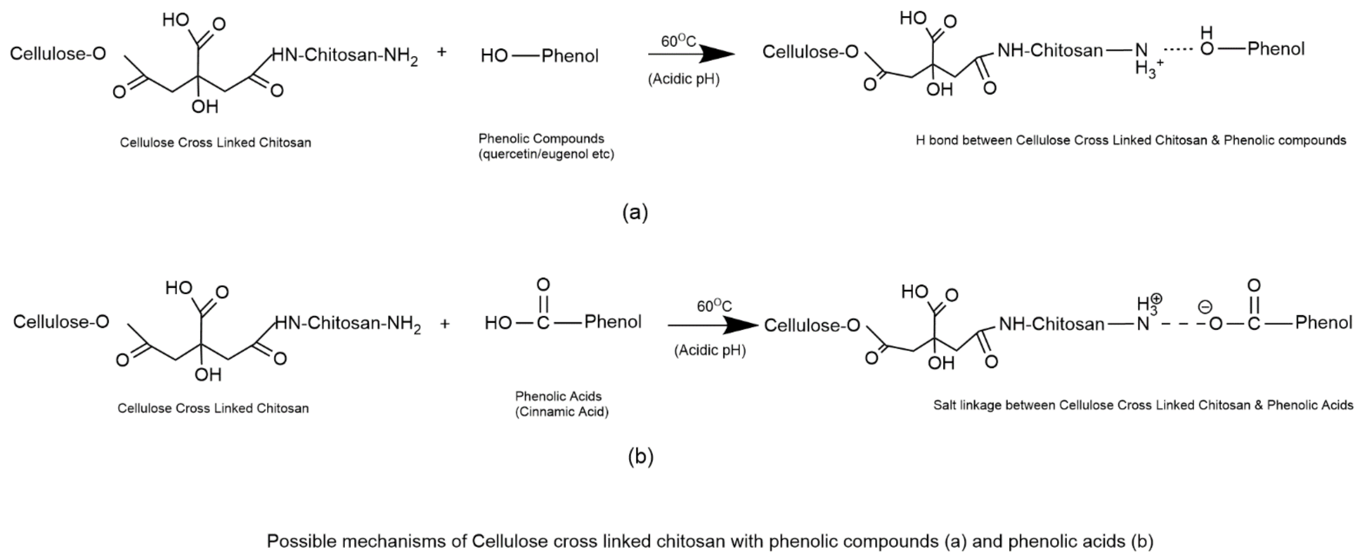


Figure 5: Possible fixation mechanism of colouring components (phenols and phenolic acids) with cellulose cross-linked chitosan, a) via Hydrogen bonding and b) via salt linkages.

Table 2: Colour values of dyed linen.

Sample no.	Dye (%shade)	L*	a*	b*	c*	h°
Standard	0	82.92	-1.09	4.65	4.78	103.25
1	10	81.37	1.25	14.77	14.83	100.61
2	20	78.29	3.99	17.15	17.61	99.07
3	30	77.87	5.35	20.33	21.02	98.4
4	50	75.14	7.58	21.53	22.83	97.38
5	100	70.41	10.02	24.61	26.57	96.4

* Average value of three determinations

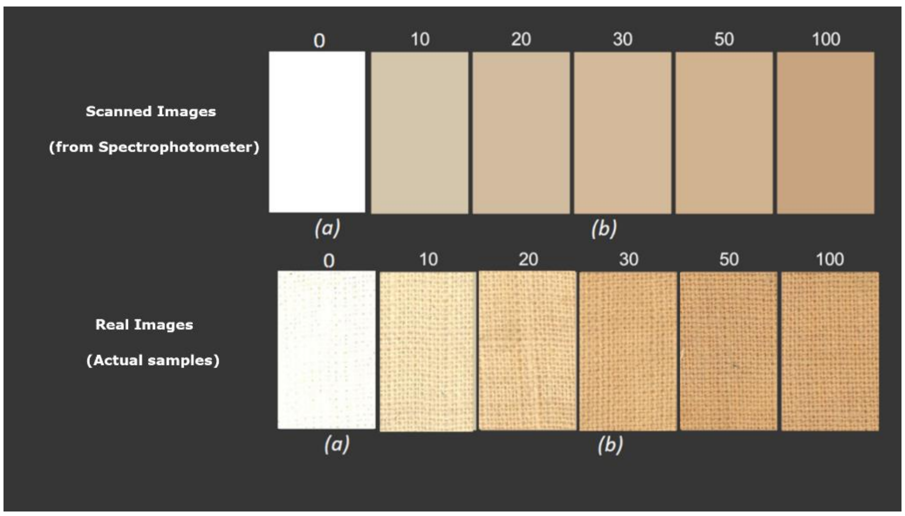


Figure 6: Scanned and real images control sample (a) and dyed samples (b) obtained from reflectance spectrophotometer.

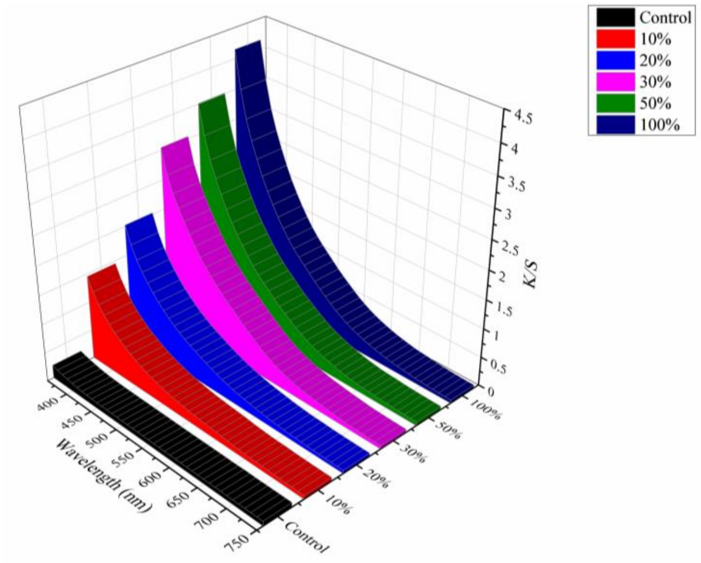


Figure 7: K/S (x - axis) vs Wavelength (y – axis) of the Control (std) and dyed linen samples (10, 20, 30, 50 and 100 % o.w.f. of *CBE* represented as 10, 20, 30, 50 and 100 %, respectively.)

As shown in Table 2, the colour values increased with an increase in shade percentage. This is obvious because with higher % (o.w.f.) of cinnamon extract, more of its compounds will be absorbed by linen fabric resulting in darker shades. Accordingly, L* value decreases with increase in shade percentage. In general, the a* values should increase with an increase in shade percentage indicating redder tones in the dyed fabric. The b* value also showed similar trends and linen dyed with higher shade percentage showed yellow tone. Hence the dyed fabrics were redder and yellower in shade. This was also visually evident in the dyed fabrics. Beautiful shades were obtained on dyed linen which can be seen in Figure 6. Most natural dyes have low to moderate affinity towards textile substrate, which necessitates the use of mordants during their application. In this research chitosan was used as a mordanting agent. Chitosan is a biopolymer with an amino group at the C_2 position, which can be protonated in acidic conditions, providing cationic sites for the attachment of anionic bioactive compounds. Moreover, chitosan is a film-forming polymer that can attach to linen in a wash-fast manner. There can be good interaction between linen and chitosan through citric acid crosslinking. The resultant ester linkages between linen and citric acid ensure that chitosan's covalent fixation results in wash durability of the chitosan treatment on linen fabric. Apart from this, there can be good interaction between the compounds in cinnamon extract and fabric through chitosan, due to the availability of hydroxyl, amino, and carboxylic acid groups. Moreover, the Schiff base can be formed between the amino groups of chitosan and aldehyde group of cinnamaldehyde [41].

3.4. Fastness properties of dyed linen

The washing fastness was evaluated as ISO 105- CO6-A1M for up to 10 washing cycles using RFD linen as the staining cloth. Rubbing fastness was evaluated according to ISO105-X12:2016 standard with RFD linen for evaluation of dry and wet rubbing fastness. The fastness properties were evaluated using a grey scale ranging from 1 to 5, where 1 is poor, 2 is satisfactory, 3 is good, 4 is very good, and 5 is excellent. Table 3 shows the fastness ratings of dyed fabrics.

Fabrics dyed with cinnamon extract showed excellent fastness (4-5) against washing. This may be due to the presence of chitosan as a mordant. Chitosan, a natural biopolymer derived from chitin, can bind dye molecules during the dyeing process. Chitosan has a positively charged amino group that can interact with negatively charged dye molecules through electrostatic interactions, assisting the dye attachment to the fabric. The dyed samples also showed satisfactory rubbing fastness. The dry rubbing fastness ranged from "very good" to "good". The wet rubbing fastness ratings were slightly lower; however, such ratings are common for textiles dyed with natural dyes. The wet rub fastness of 2-3 is generally acceptable in darker shades and printed textiles.

Table 3: Fastness ratings of dyed linen.

Sample no.	Dye (% o.w.f. shade)	Washing fastness Of Dyed fabrics (Staining to adjacent linen)	Rubbing fastness (Dry/Wet)	Light Fastness of Dyed fabrics
1	10	4-5	4/3	3-4
2	20	4-5	4/3	3-4
3	30	4-5	4/3	3-4
4	50	4-5	3-4/3	3-4
5	100	4-5	3-4/2-3	3-4

The abrasive rubbing in wet alkaline conditions might have removed the dye from the dyed linen. All the dyed samples demonstrated good fastness to light (3-4). The availability of chitosan mordant with respect to the dye can be a critical factor. Initially, biomolecules may be held by ionic interactions; however, at higher dye concentrations, after the saturation of available cationic sites, H-bonding and other weak interactions between the dye, chitosan, and fibre might have led to lower wet rub fastness.

3.5 Characterization of dyed fabrics

As shown in the FTIR spectra of dyed and control linen samples (Figure 8a), there are peaks at wavenumbers 1616, 1722, 2847, 3255 cm^{-1} in dyed linen samples, which are not present in control sample. Also, there are peaks in the range of 3241 cm^{-1} and 3386 cm^{-1} in both dyed linen and control samples. These peaks at wavenumbers 3241 and 3386 cm^{-1} may be attributed to OH groups in both dyed linen and control sample. The peaks at 3255 and 1722 cm^{-1} in dyed linen sample are attributed to NH and CO stretches respectively, and may be indicative of reaction of NH_2 group from chitosan with citric acid via an amide linkage. The peak at 2847 cm^{-1} in the dyed linen sample suggests the presence of an aldehyde group, which may be attributed to unreacted cinnamaldehyde in the dyed linen fabric. The peak at 1616 cm^{-1} in the dyed linen sample strongly suggests Schiff's base formation (N=C linkage) in the dyed linen sample. FT-IR analysis suggests the presence of secondary amino group, aldehyde group, amide group, and imine group (wavenumber 1616 cm^{-1}) stretching, which are absent in control (undyed) linen sample.

From the TGA analysis (Figure 8b), it is evident that there is no significant change in the control and dyed linen samples. The % weight-loss patterns of both control and dyed linen samples are almost identical.

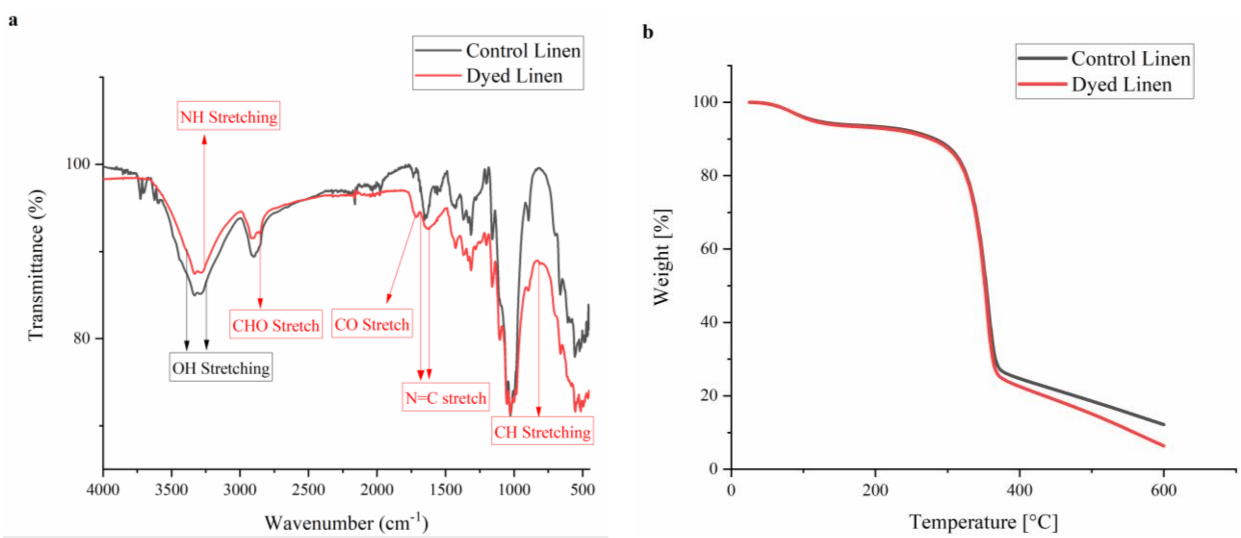


Figure 8: FTIR (a) and TGA (b) of control and dyed linen.

3.6. Mosquito repellency of dyed linen

Figure 9 shows the mosquito-repellent property of chitosan mordanted cinnamon extract-dyed linen fabric at different shade (%) after zero and ten washes. Fabric dyed with 10 % shade showed 92.85 % mosquito repellency, whereas fabric dyed with 50 % shade showed 100 % mosquito repellency which was retained after 10 washes.

The mosquito-repellent property of the dyed linen is attributed to cinnamon extract, which contains significantly higher amounts of cinnamaldehyde and various other natural compounds, which can affect mosquito sensory functions (smell and taste). It can be clearly observed from Figure 9 that 50 % (o.w.f.) dyed fabric retained its mosquito-repellent properties at 100 % even after 10 washes. This shows that chitosan effectively binds the compounds in cinnamon extract to the fabric and that the functional compounds from the cinnamon extract are retained even after 10 wash cycles.

3.7. UPF of dyed linen

The UPF values were measured using (AS/NZ) standard 4399:2017 and the results are summarized in Table 4. All the finished samples demonstrated good UV protection value with UPF rating above 15 because CBE contains natural compounds such as cinnamates, flavonoids, cinnamaldehyde, and polyphenols that inherently provide UV-absorbing or blocking properties. Chitosan itself does not exhibit any UV protection properties. Still, when used as a mordant in the dyeing process, it can form complexes with dye molecules, creating a protective layer on the fabric. This layer may have some UV-blocking properties.

3.8. Antioxidant property of dyed linen

Table 4 displays the antioxidant properties of dyed fabrics. The dyed fabrics exhibited significant antioxidant activity, attributed to the presence of phenolic antioxidants, flavonoids, and cinnamaldehyde in cinnamon bark. DPPH is a chemically stable, free radical that can receive a hydrogen atom or electron from phenolic components found in cinnamon and become stable. It has been already reported that chitosan exhibits certain antioxidant properties due to its radical-free amino group [42].

3.9. Antibacterial property of dyed linen

Table 4 shows the antibacterial activity on dyed fabric. The finished fabric samples exhibited excellent antibacterial activity, as demonstrated in Table 4 and Figure 10. The antibacterial action of cinnamaldehyde and other phenolic components of cinnamon has been well reported [43].

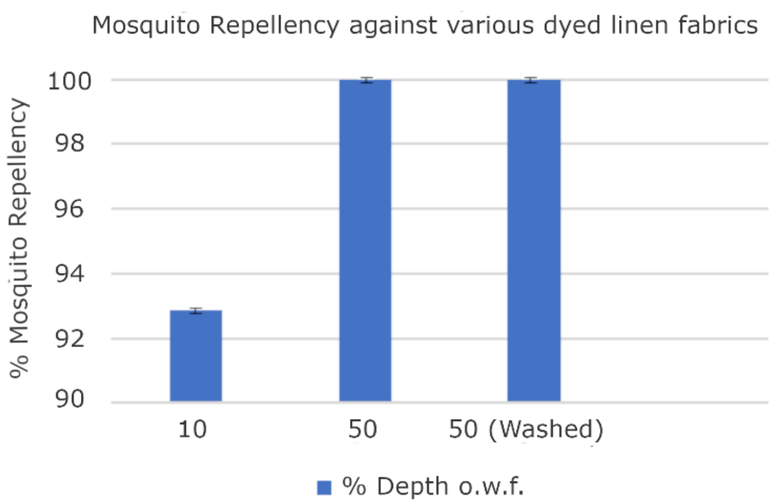


Figure 9: Mosquito repellency of dyed fabrics.

Table 4: Antibacterial Activity (%), Antioxidant activity (%) and UV properties of linen fabrics dyed using various % o.w.f. shade.

Sample no.	Dye (% shade)	Antibacterial Activity# (%)	Antioxidant Activity (%)	UPF values#	UV-A blocking (%)	UV-B blocking (%)
1	10	80	22.36	18.06	92.66	94.69
2	20	82.5	43.29	20.23	93.94	95.26
3	30	85	43.20	21.61	93.97	95.48
4	50	88.5	50.06	22.23	94.37	95.53
5	100	92.5	66.18	25.59	95.27	96.19

Average value of three determinations

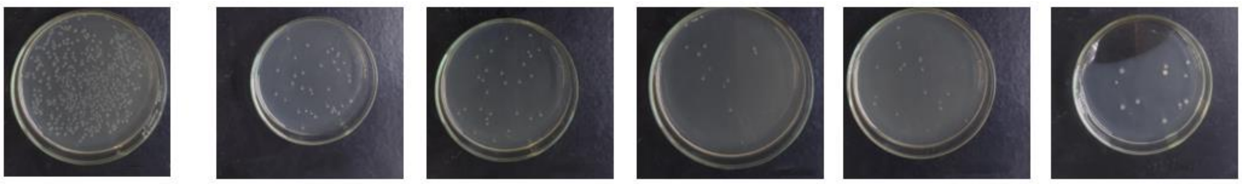


Figure 10: Antibacterial activity of control and dyed linen samples against E. Coli (a) control linen, (b) 10 % dyed, (c) 20 % dyed, (d) 30 % dyed, (e) 50 % dyed, (f) 100 % dyed.

Cinnamaldehyde is the most effective antimicrobial component found in cinnamon. Cinnamaldehyde can penetrate microorganisms by crossing the cell walls, probably damaging the cells. Chitosan has been documented to exhibit exceptional antibacterial efficacy. It can interact with the bacterial cell walls, potentially causing blockages and leakages of their cell membranes [44]. From the results it can be observed that as the shade % increases, antimicrobial activity increases. Hence, the combined action of chitosan and cinnamon exhibits a synergistic effect, resulting in significant antibacterial activity against *E. coli.*

3.10. Cost Analysis

Comparing cost analysis of natural-dyed materials is difficult due to variation in materials and processes; however, the processes involving same materials can be compared. Some literature reports involving the use of chitosan in natural dyeing have been compared. Interesting works [31, 32, 45] involving the use of chitosan mordanting in an exhaust method are available in the literature. In this work, researchers used MLR of 1:30 at 90 °C for 60 min, whereas the present work used pad-dry-cure method for mordanting. In general, application of natural dyes involves pre-mordanting using metallic or bio-mordants in exhaust mode, followed by the application of natural dyes in a similar manner. The use of continuous method over the exhaust method is already reported to be cost-effective in terms of water consumption alone [46]. In addition, savings in thermal energy, manpower cost and electricity are also added benefits.

Table 5 provides a consolidated summary of the work done to date on textiles with mosquito repellent, antibacterial, UV protective, antioxidant, and wash-durable functionalities using natural products. From this Table, it is evident that there is no work has been reported to date on the application of cinnamon bark extract on chitosan crosslinked linen to achieve wash-durable, mosquito-repellent, UV-protective, anti-bacterial, and antioxidant textile.

Table 5: Comparison of previous works done on textiles with mosquito repellent, antibacterial, UV protective, antioxidant and wash durable properties using natural products.

Sr. No	Natural Source	Substrate	Mordants used	Coloration	Mosquito Repellency (%)	Antibacterial Activity (%)		UPF	Antioxidant Activity (%)	Washing Fastness	Ref. No.
						Against *E. coli*	Against *S. aureus*				
1	Catechu	Cotton	Chitosan	Yes	–	99.80*	99.75*	–	–	4-5*	[32]
	Marigold		$CuSO_4$			99.75*	99.90*			4*	
	Turmeric		Alum			99.10*	99.25*			4-5*	
	*Values for samples where chitosan was used as mordant.										
2	Safflower (*Carthamus tinctorius L.*)	Silk	Chitosan	Yes	–	89 %	76 %	50+	–	Adequate	[31]
3	Turmeric (*Curcuma Longa*), Sandalwood (*Pterocarpus Santalinus*)	Recycled Cotton yarns	Chitosan	Yes	–	–	–	–	–	Poor	[45]
4	Essential oils of various natural sources and their microemulsions	Cotton (chitosan - sodium alginate matrix for micro emulsification followed by coating)	–	–	72.9±13.9 %	Mic 0.1-5.0 ((µl.ml^{-1})	0.1-10.0 ((µl.ml^{-1})	–	–	–	[47]
5	Henna	Cotton	No mordant (Diazotized DEET-NH_2)	Yes	100 %	98.45	98.46	35+	-	3-4	[33, 48]
					100 %	97.52	98.40	50+		3-4	
	Catechu, Chitosan (As bio-couplers)				100 % (*Wash Durable MR)	85.5	89.2	30+		4-5	
6.	*T. chebula*	Cotton	No mordant, (Diazotized ethyl anthranilate)	Yes	100 %*	99.21±0.41	98.13±0.80	50+	a.98.42±0.43	3-4	[15, 49, 50]
	Turmeric				100%*	–	–	50+	–	4-5	
	Chitosan (As bio-couplers)				100%* (*Wash Durable MR)	86.8	–	35+	–	4-5	
7.	Cinnamon Bark (*Cinnamomum Verum*)	Silk	Turmeric, Rose Petals, Acacia, Pomegranate, Alum, $FeSO_4$	Yes	–	–	–	–	–	3 (without Mordant)	[21]
										4-5 (with Mordants)	
8.	Cinnamon	Cotton Wool Blended Yarns	Alum	Yes	–	–	–	–	–	4-5	[51]

Table 5: Continue.

Sr. No	Natural Source	Substrate	Mordants used	Coloration	Mosquito Repellency (%)	Antibacterial Activity (%)		UPF	Antioxidant Activity (%)	Washing Fastness	Ref. No.
						Against *E. coli*	Against *S. aureus*				
9.	Cinnamon Bark	Wool	–	Yes	–	–	–	–	–	3	[17]
10	Cinnamon (Cinnamomum Verum) + Clove (*Syzygium Aromaticum*)	Hair	–	Yes	–	–	–	–	–	–	[23]
11.	Cinnamon Bark Extract (Aq.)	Linen	Chitosan	Yes	100 %* (Wash durable MR)	92.5 %	-	25+	66.18	4-5	This Study

4. Conclusion

In this research, the potential of CBE as a natural dye and chitosan as a mordant for linen fabric with a focus on sustainable and functional textile applications was explored. The GC-MS analysis confirmed presence of cinnamaldehyde in aqueous cinnamon bark extract (CBE). The addition of chitosan enhances the functionality of the dyed linen fabric. Owing to its antimicrobial properties, chitosan helped to protect the fabric from microbial attack and assisted the binding of the CBE functional components to the fabric, thereby providing good fastness properties. Dyed Linen fabric demonstrated several functional properties like antibacterial activity (up to 92.5 %), antioxidant activity (up to 66.18 %), UV protection (UPF 25), and mosquito repellency to a significant degree. It was established that fabric dyed with 50 % (o.w.f.) shade demonstrates 100 % mosquito repellency, which was retained even after 10 wash cycles. The covalent linkage between cinnamaldehyde and chitosan was confirmed using FT-IR analysis. UV Visible spectroscopic analysis confirmed the shift in λ_{max} of CBE upon its interaction with chitosan from 285 nm (CBE) to 279 nm in UV region. A durable, covalently bound cellulose-chitosan-cinnamaldehyde linen fabric with numerous functional properties, including antimicrobial, UV protective, antioxidant and mosquito-repellent, was successfully prepared using the reported process.

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