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Eco-Dyeing and Functional Finishing of Cotton Fabric Using a Natural Colour Derived From Lotus Seed: Enhanced Fastness Properties with Chitosan

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ABSTRACT
Medicinal plant-based dyeing introduces vibrant colours alongside antibacterial and anti-odor properties, fostering sustainability. Innovations include mass sampling for consistent pigment production. Furthermore, lotus seedpods, rich in bioactive compounds, exhibit potential in diverse fields. Chitosan, a biopolymer derived from chitin, boasts versatility in drug delivery systems, wound healing, and antimicrobial applications. This experimental inquiry delves into the dyeability and antimicrobial efficacy of cotton fabric subjected to treatment with chitosan and dyed using Lotus seeds. The investigation encompasses varied parameters such as dye concentration, duration, and temperature for fabric dyeing. The study elucidates the aqueous extraction methodology for dye from Lotus seeds, the chitosan-based mordanting techniques. Standardized assessments are utilized to gauge colour fastness characteristics, encompassing washing, rubbing, and perspiration fastness, along with assessing the antimicrobial attributes of the treated cotton fabric. The study indicates that the application of chitosan-treated cotton fabric enhances dye intensity and overall dyeing quality, consequently improving the colour fastness property of washing, rubbing, and perspiration. Additionally, the treated cotton fabric exhibits significant antimicrobial activity against common bacteria, highlighting the potential of Lotus seed-derived colourants and chitosan mordant in the development of sustainable and antimicrobial textiles. The future scope lies in optimizing the integration of Lotus seed-derived colourants and chitosan mordant for enhanced sustainability and antimicrobial efficacy in textile applications, leveraging advancements in dyeing technology and antimicrobial formulation techniques.

KEYWORDS
dyeing, functional finishing, cotton, lotus seed, colour fastness, chitosan, antimicrobial properties

INTRODUCTION

Natural dyeing has a lengthy history, having been utilized since ancient times. Initially, natural dyes were obtained from plants, insects, and animals. The initial use of natural dyes on textile fibres is estimated to have begun in Mesopotamia and India around 4000 BC. However, with the discovery of synthetic dyes in the 19th century, the use of natural dyes decreased significantly. Synthetic dyes offered a wider range of colours and were easier to use. Additionally, industrialization and globalization led to an increase in the use of synthetic dyes [1]. However, in recent years, there has been a resurgence of interest in natural dyes due to growing concerns about the environment and health hazards associated with synthetic dyes. Natural dyes are considered eco-friendly and more sustainable, and there is a niche market for textiles coloured with natural dyes. Natural dyeing is the process of dyeing textile fibres and fabrics using plant materials. Natural dyes are derived from various plant components such as leaves, bark, flowers, fruits, and roots [2]. They possess unique qualities such as calming colours, biodegradability, safety, and antimicrobial resilience. However, the usage of natural dyes has decreased due to the availability of inexpensive synthetic dyes. Nevertheless, there is a growing interest in reviving the use of natural dyes, especially in the field of textile arts [3]. Recent research focuses on the application of natural dyes in dyeing textile fabrics to reduce health hazards and pollution, as well as enhance dyeing quality and antimicrobial activity. Challenges in natural dyeing include difficulty in colour reproduction and the need for education about natural colourant use. Innovations in natural dye production include mass sampling of dye plants for consistent pigment production [4].

Natural dyeing with medicinal plants is a sustainable and eco-friendly method that offers not only vibrant colours but also medicinal properties. Various plants such as *Hemigraphis colourata, Bacopa monnieri, Lawsonia inermis, Hibiscus sabdariffa, Rheum officinale, Sambucus nigra,* and *Chamomilla recutita* have been studied for their dyeing potential and medicinal characteristics. These plants have been used to develop herbal composites and dye solutions that can be applied to fabric samples using different techniques such as pad-dry cure process, radiation methods, and ultrasonic dyeing equipment [5]. The finished fabrics show good antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*, as well as anti-odour properties. The natural dyeing method using plant materials has a lower allergenic potential compared to synthetic methods. However, achieving full coverage of hair colour with plant materials may be challenging, and the selection of additives with appropriate pH values is important for favourable results [6].

Natural dyeing involves the use of plant extracts and compounds to colour textiles. Different natural dyes have been studied, and their active compounds have been identified. For example, madder root extract contains salicylic acid, quercetin, ellagic acid, and benzoic acid as main compounds [7-8]. Cochineal extract contains rutin, kampherol, myricetin, quercetin, and salicylic acid as main compounds. Impatiens balsamina extract, chloroacetic acid, and an organic carboxylic acid compound are used in a natural plant textile fabric dyeing agent [9]. A natural textile dye includes a garden balsam extract, *Cinnamomum camphora* leaf extraction liquid, and an organic carboxylic acid compound. These compounds contribute to the colour and properties of the dyed fabrics, providing stability, brightness, and environmental friendliness [10].

Lotus seedpods are the by-products of lotus plants and have been studied for their phytochemicals, biological activities, and industrial applications. They contain various phytochemicals such as proanthocyanidins, flavonoids, alkaloids, and terpenoids, which exhibit bioactivities like antioxidation, antibacterial, and neuroprotection. Additionally, lotus seedpods have been explored for their potential as a source of polysaccharides, which have shown antioxidant and α-glucosidase inhibitory effects, making them suitable for use as natural antioxidants and hypoglycemic substitutes. Furthermore, gas-assisted combined with glycerol extraction (GAGE) has been proposed as a green and efficient method for recovering polyphenols from lotus seedpods, which have demonstrated antioxidant activities [11]. Overall, lotus seedpods have shown promise in various fields such as the food industry, medicine, and environmental sustainability. Lotus seedpods have various medicinal uses. They are rich in phytochemicals such as proanthocyanidins, flavonoids, alkaloids, and terpenoids, which exhibit bioactivities like ameliorating cognitive impairment, antioxidation, antibacterial, anti-glycative, neuroprotection, and anti-tyrosinase activities [12]. The seed epicarp of Nelumbo nucifera Gaertn. has been found to have higher extractable total phenolic content and flavonoid content compared to the seed and seed pod. It also showed higher antioxidant activity, including DPPH and ABTS radical scavenging, reducing power, and hydrogen peroxide scavenging activities [11]. Lotus seedpod extract has been shown to have hepatoprotective effects, reducing intracellular lipid accumulation, oxidative stress, and apoptosis in human hepatocytes. Additionally, lotus seedpod extract has been used for the treatment and prevention of kidney diseases, as it can suppress inflammatory factors, enhance antioxidant enzyme activity, and reduce kidney oxidative pressure [13-14]. Overall, lotus seedpods are considered a functional food with multiple therapeutic benefits, including anti-adipogenic, antioxidant, antitumor, cardiovascular, hepato-protective, anti-inflammatory, and hypoglycemic effects.

Chitosan is a biopolymer derived from chitin, and it has gained attention in various fields due to its unique properties. It is biocompatible, biodegradable, and can be easily modified for specific applications. Chitosan has been extensively used in drug delivery systems, allowing for targeted and sustained release of drugs. Chemical modifications have improved its solubility, stability, and functionalization ability, making it suitable for biomedical applications [15,16]. Chitosan's versatile properties, such as antibacterial, antifungal, and non-toxicity, make it a smart material for different applications, including wound healing, tissue engineering, and gene therapy [17].

Table 1. Research Studies on Lotus Methods and Results

Author Name	Title of Paper	Methods Used	Results
Wu et al. (2021)	Effect of lotus seedpod oligomeric procyanidins on AGEs formation in simulated gastrointestinal tract and cytotoxicity in Caco-2 cells.	• The methods used in this study involved in vitro experiments and analysis of various cellular and molecular parameters to assess the effects of LSOPC and CC on AGEs formation and Caco-2 cell protection	• LSOPC and CC protected Caco-2 cells from AGEs attack. They inhibited digestive enzyme activity, reactive oxygen species, RAGE-p38MAPK-NF-κB signalling pathway, inflammatory factors (tumour necrosis factor-alpha, interleukin 6), and adhesion factors (intercellular cell adhesion molecule-1, vascular cell adhesion molecule-1) to protect Caco-2 cells.
Nortjie et al. (2022)	Extraction Methods, Quantitative and Qualitative Phytochemical Screening of Medicinal Plants for Antimicrobial Textiles: A Review	• The paper delves into examining different facets of creating antimicrobial finishes. This encompasses exploring extraction techniques, conducting qualitative and quantitative assessments of phytochemicals, and advancing the production of antimicrobial-treated textiles through the utilization of diverse agents.	• Antimicrobial finishings can be effective in destroying pathogens on surfaces and textiles, providing a solution to the problem of microbial contamination. • The analysis of various aspects of producing antimicrobial finishings provides valuable insights for the development of antimicrobial textiles
Zamora-Mendoza et al. (2022)	Antimicrobial Properties of Plant Fibres	• The antibacterial activity of the fibres was evaluated using the AATCCTM100-2004 method with the use of ethylene oxide in the sterilization process.	• The antibacterial activity of the fibres was evaluated using the AATCCTM100-2004 method, and they showed efficient antibacterial properties against *Staphylococcus aureus* and *Escherichia coli*. • The antibacterial reduction rate of the fibres was found to be more than 99%, indicating their effectiveness in killing bacteria.

Author Name	Title of Paper	Methods Used	Results
Selvam et al. (2022)	Embellishing 2-D MoS2 Nanosheets on Lotus Thread Devices for Enhanced Hydrophobicity and Antimicrobial Activity	• MoS2 nanosheets were synthesized using a coprecipitation method with sodium molybdate dihydrate and thioacetamide as precursors. These nanosheets were then used for MoS2 particle growth on cellulose threads extracted from lotus peduncles. • The size, crystallinity, and morphology of the pure and MoS2-coated fibres were studied using X-ray diffractometry (XRD) and scanning electron microscopy (SEM). The XRD pattern showed that the MoS2-coated fibres had more crystallinity than the pure fibres, and SEM images confirmed the growth of MoS2 nanosheets on the threads.	• The MoS2-coated threads showed enhanced hydrophobicity and antimicrobial activity compared to the pure threads. • EDX elemental analysis confirmed the presence of MoS2 nanosheets on the threads. • Antimicrobial studies demonstrated that the MoS2-coated threads exhibited better resistance against *Escherichia coli* and *Candida albicans* compared to the pure threads. • The water absorbency assay showed that the MoS2-coated threads had a higher absorption rate and restricted wicking, indicating their improved hydrophobicity.

Its ability to encapsulate and deliver substances has led to advancements in medical and pharmaceutical applications. Chitosan also finds applications in the textile industry, where it imparts antimicrobial and other biological activities to fibres and fabrics [18]. Chitosan, a naturally occurring polymer derived from chitin found in the shells of animals, has various medicinal uses. It has been studied for its non-toxicity, biodegradability, biocompatibility, immunostimulant, anticancer, antibacterial, and antimicrobial activity [19]. Chitosan can be used in the treatment and prevention of various illnesses, as well as in diagnostic and therapeutic applications for managing malignancy. Chitosan can also be combined with other active substances, such as metals, drugs, and natural compounds, to enhance its antibacterial effects and application potential [20]. Additionally, chitosan derivatives, such as chitosan Schiff bases, have shown increased antimicrobial activity against bacteria and yeasts, making them potential candidates for antimicrobial prevention in various fields [21]. Chitosan and its derivatives have also been extensively studied for their antibacterial, antitumor, antioxidant, and tissue regeneration effects, making them suitable for drug delivery and wound healing applications. Overall, chitosan and its derivatives have promising potential in the medical field for various therapeutic effects and drug delivery functions [22-24].

Table 2. Research Studies on Chitosan Methods and Results

Author Name	Title of Paper	Methods Used	Results	Conclusions
Mukarram *et al. (2023)*	Chitosan-induced biotic stress tolerance and crosstalk with phytohormones, antioxidants, and other signalling molecules	• The paper discusses the antimicrobial and insecticidal potential of chitosan. • The paper explores the correspondence of chitosan with phytohormones and antioxidant metabolism.	• Chitosan supports plant growth and development and protects against microbial entities. • Chitosan has active correspondence with phytohormones and antioxidant metabolism.	• Chitosan has antimicrobial and insecticidal potential and supports plant growth. • Chitosan interacts with phytohormones, antioxidants, and signalling molecules in plants.
Enright *et al*. (2023)	Synthesis and Antibiotic Activity of Chitosan-Based Comb-like Co-Polypeptides	• Synthesis of chitosan-based comb-like co-polypeptides • Ring-opening polymerization of N-carboxy anhydride of l-lysine and l-leucine	• Chitosan-based graft copolymers showed activity against clinically significant pathogens. • The copolymers disrupted biofilm formation.	• Synthetic chitosan-based copolypeptides have potential as antimicrobial agents. • These copolymers exhibit activity against pathogens and disrupt biofilm formation.
Muñoz-Tebar *et al. (2023)*	Chitosan Edible Films and Coatings with Added Bioactive Compounds: Antibacterial and Antioxidant Properties and Their Application to Food Products: A Review	• Incorporation of plant extracts into chitosan films • Evaluation of antimicrobial and antioxidant properties	• Chitosan films and coatings have excellent antimicrobial and antioxidant properties. • Incorporating natural extracts enhances the properties of chitosan.	• Chitosan films and coatings with added bioactive compounds have antimicrobial and antioxidant properties. • Further research is needed to expand the applications of chitosan coatings.

Author Name	Title of Paper	Methods Used	Results	Conclusions
M. Costa *et al. (2022)*	Insights into the Biocompatibility and Biological Potential of a Chitosan Nanoencapsulated Textile Dye	• Nanoencapsulation of yellow everzol textile dye with chitosan • In vitro assays and cell infection model for biological activity evaluation	• Yellow everzol nanoparticles had no deleterious effects on HaCat cells. • Yellow everzol nanoparticles showed significant antimicrobial activity and inhibited biofilm formation.	• Chitosan nano-encapsulated textile dye showed biocompatibility and antimicrobial activity. • The dye nanoparticles effectively managed MRSA infection in cell models.
Rezaei F. (2022)	Antibacterial activity of chitosan-based nanohybrid membranes against drug-resistant bacterial isolates from burn wound infections	• Chitosan-based nanocomposites with ciprofloxacin effectively reduce drug-resistant bacterial isolates. • Nanosystems provide an opportunity for effective antibiotic treatment by improving antibacterial efficacy.	• Chitosan-based nanocomposites with ciprofloxacin effectively reduced the susceptibility of drug-resistant bacterial isolates. • Chitosan/SMMT/CIP was the most effective nanocomposite in terms of antibacterial activity.	• Antimicrobial biomaterials were introduced to overcome drug resistance. • Chitosan-based nanocomposites with ciprofloxacin showed promising results against drug-resistant bacterial isolates.

Today, the global emphasis on natural dyeing and sustainability is growing exponentially. Increasing awareness among people has underscored the necessity for textiles dyed with natural substances. In a recent study, I explored the potential of lotus seeds as a natural dye for cotton fabric. To enhance colour retention and durability, the cotton fabric was meta-treated with Chitosan powder. Subsequently, the treated samples underwent rigorous testing to evaluate various properties such as washing, rubbing, and lightfastness. Additionally, antimicrobial properties were assessed to gauge the fabric's potential to resist microbial growth.

EXPERIMENTAL

Materials and Methods

In this experimental study, exclusively 100% cotton fabric served as the primary material. The procurement of the fabric took place at the local market situated in Pune, Maharashtra. Additionally, the essential components for the experiment, namely lotus seed powder and Chitosan, were also sourced from Pune's local market.

Aqueous extraction

The extraction of dye from lotus seeds was carried out using the aqueous method. Initially, a beaker containing 300ml of water was prepared. Once the dyeing bath temperature reached 50 degrees Celsius, the lotus seed powder was introduced. Fifteen grams of dye were incorporated into the 300ml water. The dye solution underwent boiling at 70 °C for 40 minutes. Subsequently, the solution was subjected to double filtration through filter paper, resulting in a prepared and refined dye solution suitable for the dyeing process.

Mordanting and dyeing Procedure

The experiment involved treating samples under various time and temperature conditions, employing chitosan as a mordanting agent. Chitosan, a weak base, exhibits insolubility in water and organic solvents but can be dissolved in dilute aqueous acidic solutions (pH < 6.5), facilitating the conversion of glucosamine units into a soluble form, R–NH3+. Meta mordanting was conducted before dyeing the samples, aiming to enhance the dye's fixation onto the material. The dyeing process relied on three primary factors: dye concentration, time, and temperature. Dye concentration levels were categorized as low (15 g), medium (20 g), and high (25 g), while time durations were classified as short (70 min), medium (80 min), and long (90 min), and temperatures were categorized as low (60 °C), medium (70 °C), and high (80 °C) [25,26].

Table 3. Various levels and factors of dyeing

Factor Variable	Low	Medium	High
Dye Concertation (g)	15	20	25
Time (Minutes)	70	80	90
Temperature (°C)	60	70	80

Table 4. Sample coding for dyeing the samples

Sample code	Dye Concertation (g)	Time (Minutes)	Temperature (°C)
S1	15	70	60
S2	15	80	70
S3	15	90	80
S4	20	70	60
S5	20	80	70
S6	20	90	80
S7	25	70	60
S8	25	80	70
S9	25	90	80

Colour fastness assessment

The study examined the varied colour fastness properties of woven cotton fabrics. The aspect of washability, which is a crucial element in textile appraisal, refers to the ability of a dyed or printed fabric to retain its colour fastness after undergoing laundering processes. Standardized protocols, such as ISO 105-C06:2010, are playing a pivotal role in the execution of systematic washing fastness tests, thus, they are making the test more reliable and comparable. Another very important element in the textile evaluation is rubbing fastness, especially in the context of dyed or printed textiles, as it is a measure of the ability of the fabric colour to resist rubbing or abrasion, which mimics real-world wear and laundering conditions. The approved AATCC Test Method 8-2016 by the American Association of Textile Chemists and Colourists (AATCC) defines processes for measuring the colourfastness to rubbing using a crockmeter device under both dry and wet conditions. Similarly, standardized procedures are available for assessing perspiration fastness, and are developed to achieve consistent and reliable results. One widely acknowledged standard in this domain is the ISO 105-E04:2013, which was adopted by the International Organization for Standardization (ISO) and is used to evaluate the colourfastness of textiles in acidic and alkaline perspiration.

Antimicrobial Test

AATCC Test Method 100-2019, a guideline from the American Association of Textile Chemists and Colourists (AATCC), defines an approach which quantifies reductions in bacterial populations due to exposure to treated materials [27]. The broad process described in 'AATCC Test procedure 100- 1999, Antibacterial Finishes on Textile Materials: Assessment of' with changes served as the foundation for the technique used to assess the qualitative and quantitative antibacterial properties of textile materials. As indicated in the AATCC Test Method, textile swatches were 'inoculated' with a test or challenge bacterium. After incubation, the bacteria were eluted from the swatches with defined quantities of extraction solution. The amount of bacteria in this extraction solution was then quantified for each treated textile sample to allow for comparison. In the AATCC Test Method, the treated specimen's per cent decrease was determined and compared. The test approach was discovered to be more versatile and When just the final population densities were compared, the process performed successfully [28].

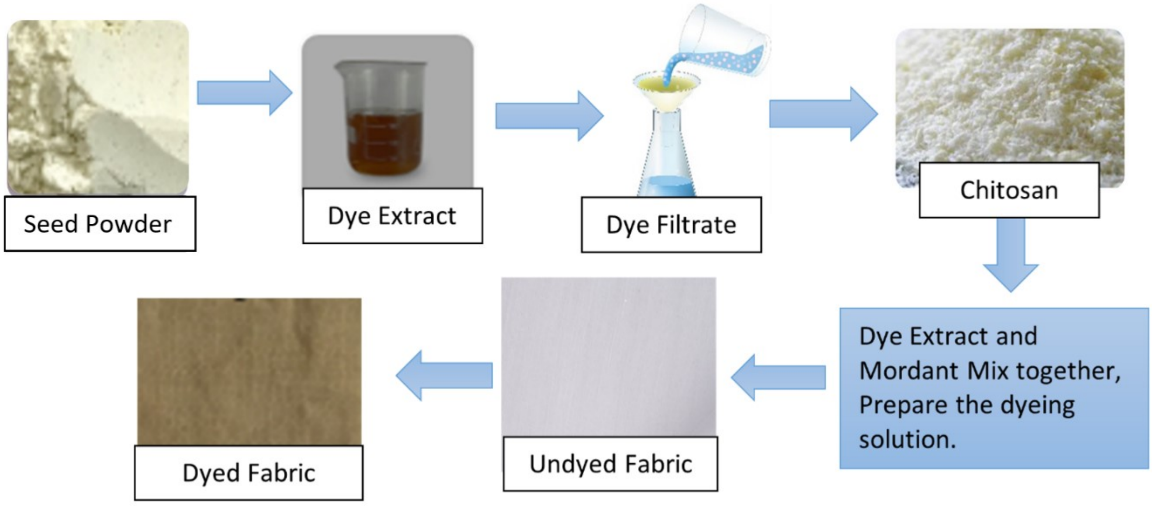

Figure 1. Mechanism Between Natural Dyes and Fabric

RESULTS AND DISCUSSION

The experimental investigation yielded insightful results regarding the colour-fastness properties of cotton fabric. Washing fastness tests revealed varying degrees of colour retention post-laundering, indicative of the fabric's ability to withstand washing processes without significant colour loss. Evaluation of rubbing fastness demonstrated diverse levels of resistance to abrasion and rubbing, reflecting the durability of the fabric's colour under simulated wear conditions. Additionally, the assessment of perspiration fastness unveiled the fabric's resilience to acidic and alkaline perspiration, providing valuable insights into its colourfastness in real-world usage scenarios. Furthermore, examination of antibacterial properties indicated the effectiveness of textile treatments in reducing bacterial populations upon exposure, underscoring the potential of such treatments in enhancing textile hygiene.

Washing Fastness

The experiment that we performed involved the dyeing of the samples with lotus seed dye. Then, we compared whether they absorbed the dye better after the previous mordanting or not using chitosan. Mordanting was the process of treating the fabric with a mordant, which was the substance that enhanced the dye-fibre association, hence resulting in dye-fastness and intense colour.

In the case of non-mordanted samples, the grades ranged between 2 to 3 respectively, and mordanted samples had grades ranging from 4 to 5. These differences indicated that mordanting with chitosan led to improved dye intensity and overall dyeing quality of the textile material when compared to non-mordanted fabrics.

The findings showed that mordanting with chitosan was a potential way for the dyeing process and produced great fastness properties. This upgrade was more evident in samples with higher dye concentrations, longer dyeing times, and elevated temperatures than left samples, which always achieved higher fastness grades compared to their un-mordanted counterparts. This implied that chitosan mordanting functionalized the lotus seed dyeing, which increased the adherence to the fabric and consequently irradiated more durable.

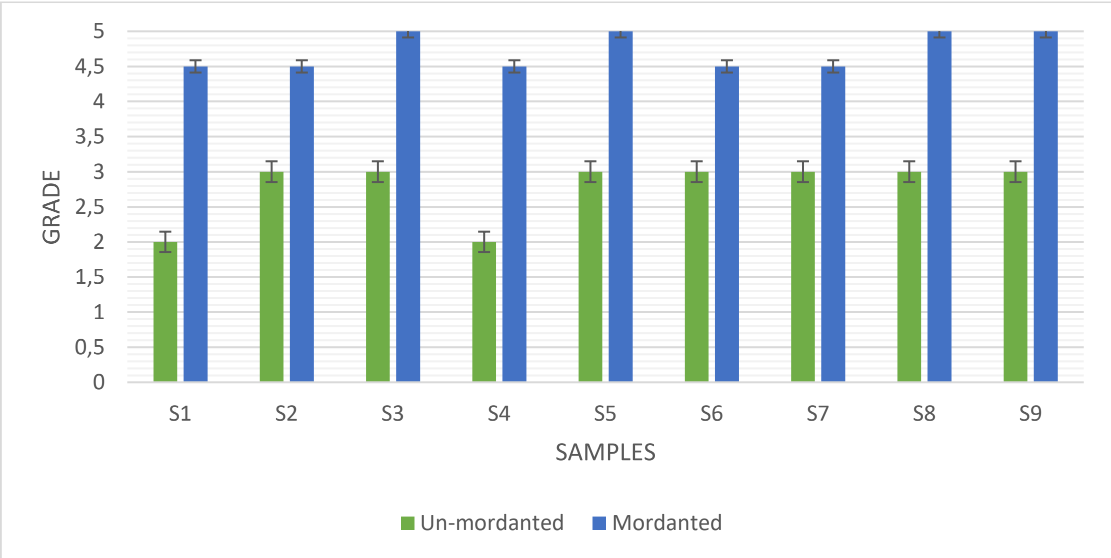

Figure 2. Washing fastness property

Rubbing fastnesses

The rubbing fastness properties of cotton fabric dyed with a natural colour derived from Lotus seed and enhanced dyeability with chitosan were assessed through a comprehensive series of tests. Nine fabric samples denoted as S1 to S9, underwent varying dye concentrations, time durations, and temperatures to evaluate their rubbing fastness performance. In the wet rubbing test without mordanting, the results ranged from grade 2 to 3, indicating moderate to good resistance to rubbing. However, upon mordanting, there was a notable improvement in wet rubbing fastness, with most samples achieving grades 4 to 5, indicating excellent resistance to wet rubbing.

Similarly, in the dry rubbing test without mordanting, the samples showed fair to good rubbing fastness, ranging from grade 2 to 3. Yet, after mordanting, the dry rubbing fastness significantly improved, with most samples achieving grades 4 to 5, signifying excellent resistance to dry rubbing. It

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is worth noting that the highest dye concentration (25 g) generally resulted in superior rubbing fastness properties compared to lower concentrations (15 g and 20 g), particularly when mordanted. Additionally, longer dyeing times and higher temperatures tended to enhance rubbing fastness, as evidenced by the higher grades achieved in samples subjected to prolonged dyeing times and elevated temperatures.

These findings underscore the efficacy of Lotus seed-derived natural colour, combined with chitosan as a dyeability enhancer, in producing cotton fabrics with exceptional rubbing fastness properties. This is especially evident when optimal dye concentrations, dyeing times, and temperatures are employed, alongside mordanting treatments.

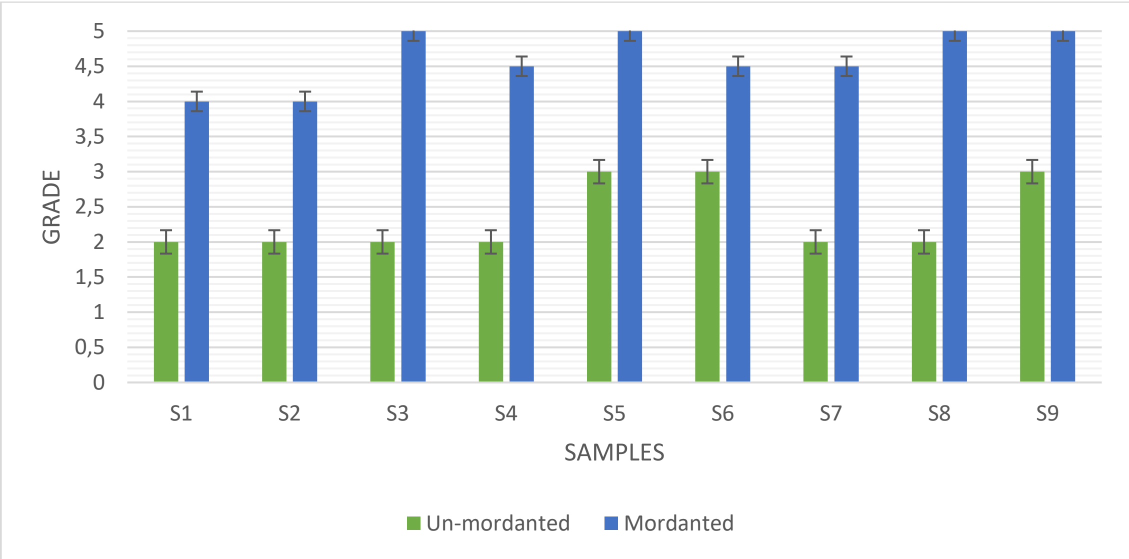

Figure 3. Wet Rubbing fastness properties

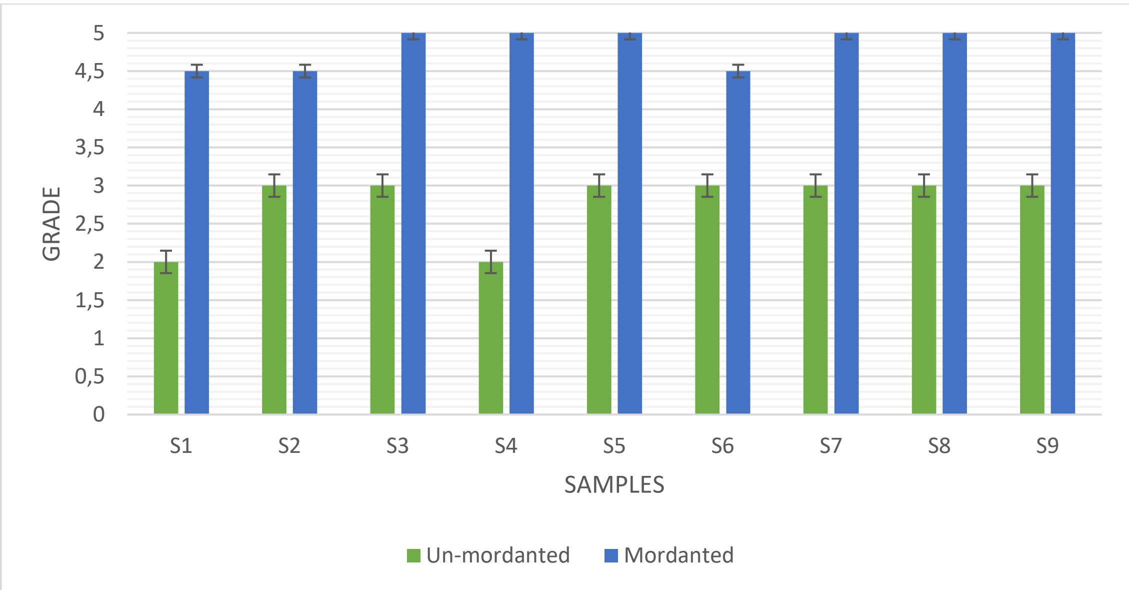

Figure 4. Dry rubbing fastness properties

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Perspiration fastness

The perspiration fastness of cotton fabric dyed with a natural colour derived from Lotus seeds and enhanced dyeability with chitosan mordant was evaluated using a grading system ranging from 1 (very poor) to 5 (excellent). The results, as depicted in the provided table, illustrate the varying grades achieved under different conditions. Across the samples, the application of chitosan mordant generally resulted in improved perspiration fastness compared to un-mordanted samples. Specifically, samples treated with chitosan displayed grades ranging from fair to excellent, with most achieving grades of 4 to 5. This suggests a positive impact of chitosan mordant in enhancing the perspiration fastness of the Lotus seed-derived natural colour on cotton fabric.

Furthermore, variations in dye concentration, time, and temperature during the dyeing process influenced the resulting colourfastness grades. Higher concentrations of dye and longer dyeing times tended to yield better perspiration fastness grades, particularly when combined with chitosan mordant treatment. Additionally, higher dyeing temperatures generally correlated with improved colour retention under perspiration conditions.

These findings underscore the potential of Lotus seed-derived natural colour, augmented with chitosan mordant, as a promising option for dyeing cotton fabric with satisfactory perspiration fastness, contributing to the development of more durable and sustainable textile materials.

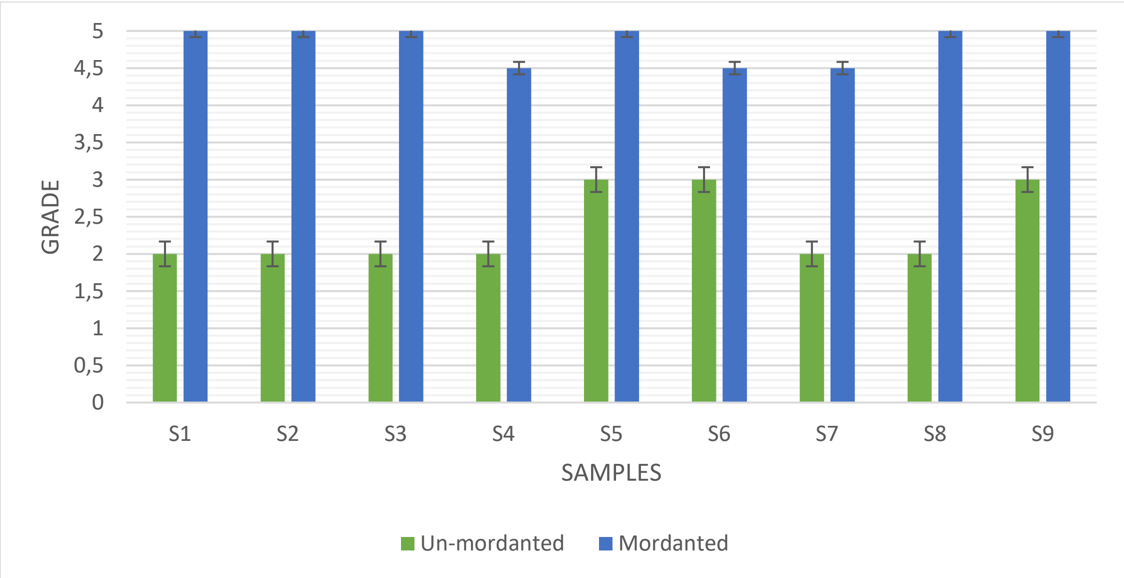

Figure 5. Acidic Perspiration fastness property results

The effect of dye concentration, time, and temperature on the dyeability of cotton fabric by using a natural colour extracted from Lotus seed with chitosan mordant is a very important issue in textile research. Dye concentration refers to the amount of dye in the dyeing solution, time denotes the

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duration of the dyeing process, and temperature indicates the thermal conditions under which dyeing takes place. These parameters have critical roles in the dyeing process and consequently influence the quality of the dyed fabric.

The concentration of dye determines the degree of saturation and intensity of colour transferred to the fabric. The other factor is time which affects the rate of dye diffusion and fixation on the fabric substrate.

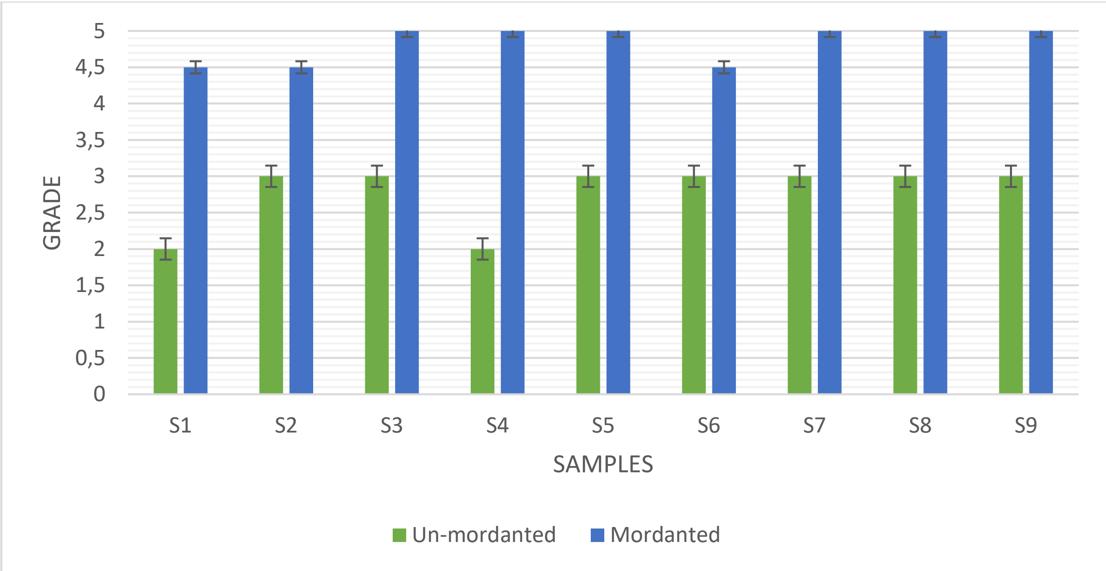

Figure 6. Alkaline Perspiration fastness property results

Longer dyeing times enable better penetration of the dye molecules into the fabric fibres, resulting in more uniform and durable colouration. Temperature is a catalyst in the dyeing process, which speeds up molecular movement and facilitates dye absorption by the fabric. The optimum temperature conditions will lead to better dye diffusion and bonding, which will in turn improve the colourfastness and wash durability of the dyed cotton fabric.

Moreover, the use of natural colourants derived from Lotus seed has ecological and sustainability benefits that are in line with the growing demand for environmentally friendly textile production methods. Chitosan as a mordant increases the affinity of the dye molecules to the fabric substrate, thus improving dye fixation and wash fastness properties. Through the investigation of the interaction between dye concentration, time, and temperature together with the use of natural colourants and chitosan mordant, researchers aim to optimize the dyeing process parameters for better dye yield, colourfastness, and overall quality of dyed cotton fabric, thus contributing to the development of sustainable and eco-friendly textile dyeing technology.

Antimicrobial properties

In this study, the antimicrobial efficacy of cotton fabric treated with a natural colour derived from Lotus seed, enhanced with chitosan mordant, was investigated. The experiment aimed to assess the dyeability of the fabric as well as its antimicrobial properties following treatment. The cotton fabric underwent a dyeing process using the natural colour extracted from Lotus seed, and chitosan was employed as a mordant to enhance the dyeing process and potentially impart additional antimicrobial properties.

The results of the antimicrobial tests revealed promising outcomes. The treated cotton fabric exhibited notable antimicrobial activity against a range of microorganisms. This antimicrobial effect is attributed to the inherent properties of Lotus seed-derived colourant and the supplementary enhancement provided by chitosan as a mordant. The combination of these components not only facilitated effective dyeing of the cotton fabric but also conferred antimicrobial functionality, thereby potentially expanding the utility of cotton textiles in various applications where microbial control is desired.

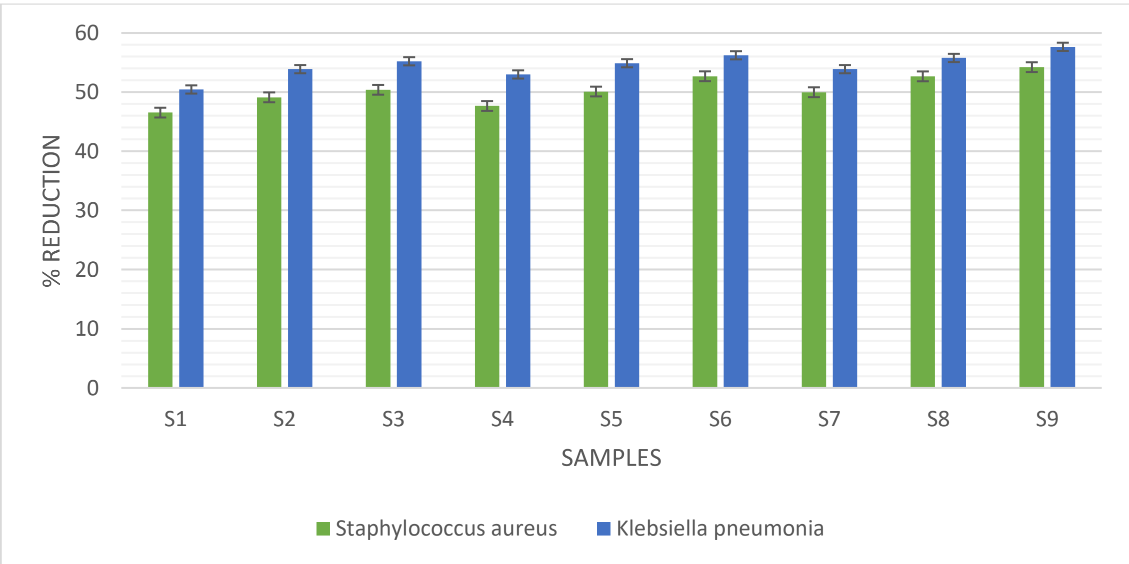

Figure 7. Antimicrobial results against *Staphylococcus aureus* and *Klebsiella pneumonia*

Furthermore, the antimicrobial activity of the treated cotton fabric was found to be durable, suggesting the feasibility of its long-term application in practical settings. The incorporation of natural colourants and chitosan mordant in textile dyeing processes presents an environmentally friendly and sustainable approach, minimizing the reliance on synthetic antimicrobial agents that may have adverse ecological impacts. This study underscores the potential of utilizing natural colourants derived from Lotus seed in conjunction with chitosan mordant to impart antimicrobial properties to cotton fabric. Further research may delve into optimizing the treatment process parameters and exploring additional

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applications of such treated textiles in diverse fields, including healthcare, apparel, and home textiles, where antimicrobial functionality is of paramount importance.

Table 5. Dyed samples Images according to sample codes

Sample code	Dyed sample
S1	
S2	
S3	
S4	
S5	
S6	
S7	
S8	
S9	

Field Emission Scanning Electron Microscopy

Field Emission Scanning Electron Microscopy is an advanced imaging method utilized for examining the surface morphology and structure of materials with exceptional precision. By employing a stream of electrons, it generates high-resolution images, offering intricate details regarding the sample's surface topography. Analysis of SEM images has revealed the remarkable antimicrobial efficacy of Lotus seeds, along with the consistent application of uniformity onto the fabric surface. Figures 7 to 10 exhibit compelling evidence, clearly showcasing the contrast between surfaces treated with and without the mordant.

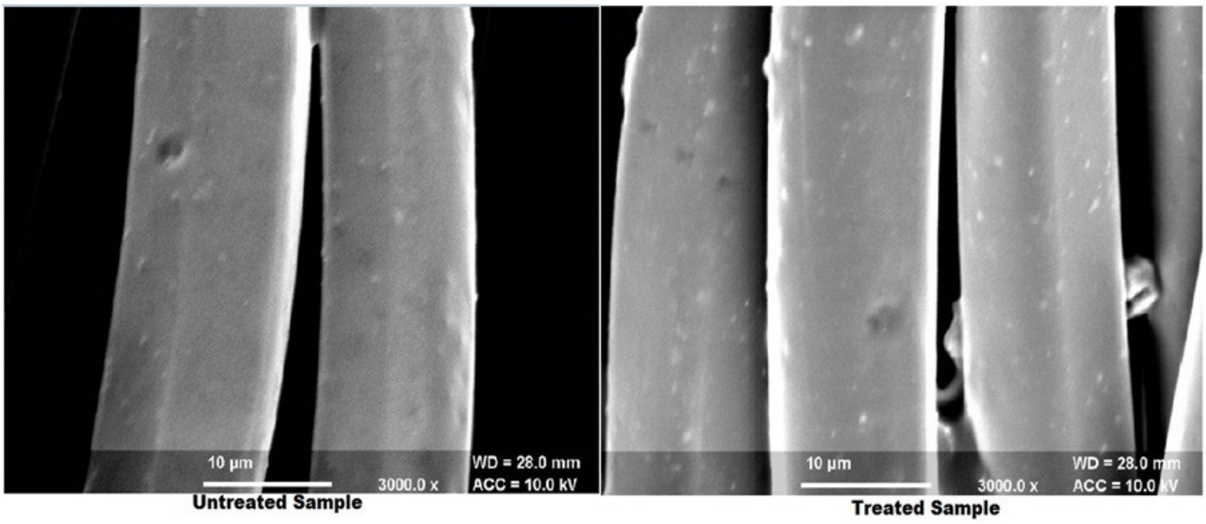

Figure 8. FeSem images of cotton fabric without mordanting and with mordanting

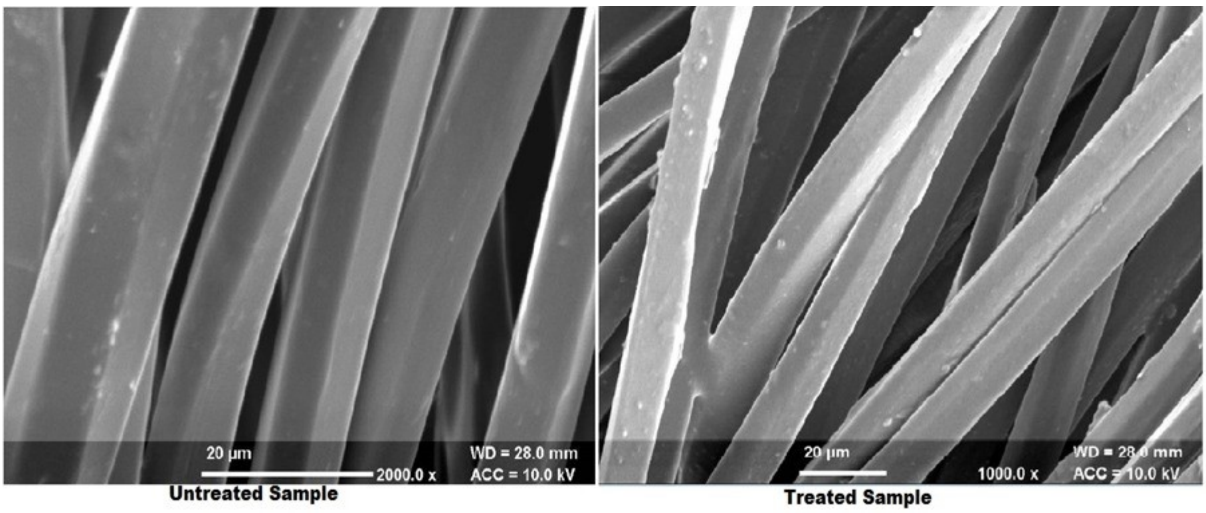

Figure 9. FeSem images of cotton fabric without mordanting and with mordanting

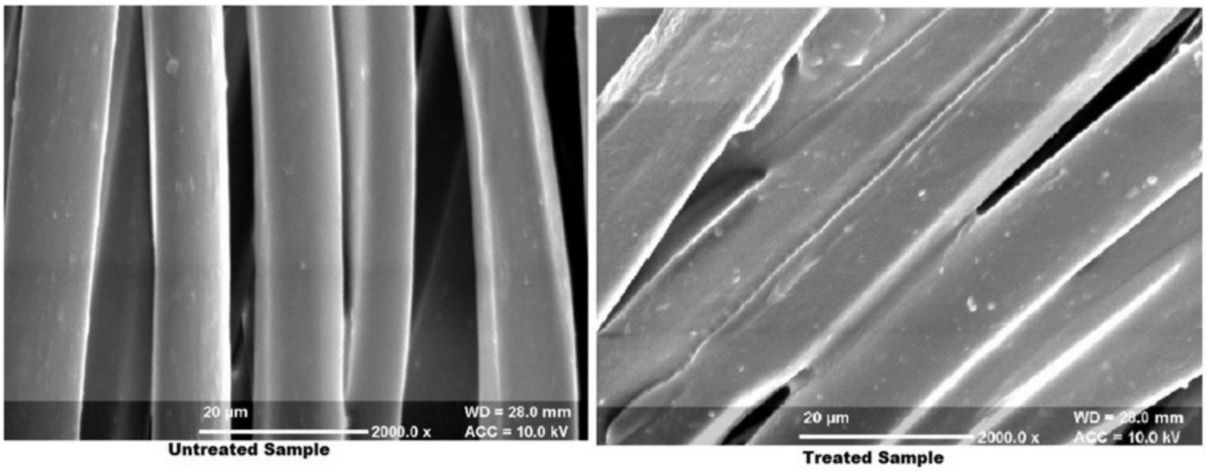

Figure 10. FeSem images of cotton fabric without mordanting and with mordanting

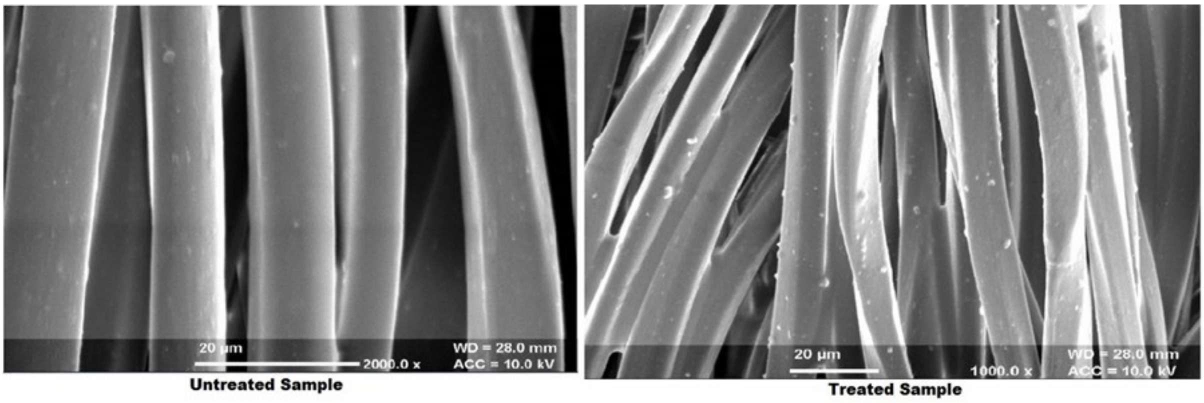

Figure 11. FeSem images of cotton fabric without mordanting and with mordanting

This study explores the complex interplay of dye concentration, time, and temperature in intensifying the antimicrobial properties of cotton fabric treated with a natural colour extracted from Lotus seeds as well as chitosan as a mordant to improve dyeability. Using meticulous experimentation, dye concentration (g), time (minutes), and temperature (°C) are systematically changed to evaluate their influence on the final antimicrobial efficacy of the treated fabric. The study aims to achieve the most successful dyeing conditions through precise optimization of these parameters, thus maximizing the antimicrobial properties of the fabric. The use of the natural colour derived from lotus seeds and chitosan as a mordant is a sustainable approach to enhancing the functional properties of textiles. Such research offers a wide range of applications in fields like healthcare, apparel, and beyond, where antimicrobial textiles are essential in protecting against microbial threats and promoting hygiene. The study provides a clear picture of the dyeing process, which is a major step towards the development of textile technology and the provision of new solutions for industries that use antimicrobial textiles.

CONCLUSION

This experimental research gives a thorough understanding of the dyeability and antibacterial properties of cotton fabric that has been treated with Lotus seed-derived natural colour and chitosan mordant. The study is a systematic approach that explains the aqueous extraction of dye from lotus seeds, the mordanting process using chitosan, and dyeing under varying concentrations, time, and temperature. Investigation shows a substantial increase in colour fastness properties, such as washing, rubbing, and perspiration fastness, after the application of chitosan mordant. Interestingly, mordanted samples show increased dyeing power and better dyeing quality which results in improved resistance to washing and simulated wear. The results emphasize the importance of chitosan in the process of dye adsorption on the fibres of the fabric, which consequently leads to colour fastness and durability. Moreover, the study provides the antimicrobial effectiveness of the treated cotton fabric against a range of microorganisms. The antimicrobial activity, resulting from the synergistic action of the Lotus seed-based dye and chitosan mordant, suggests the possible use of these natural components in the development of textiles with intrinsic microbial control properties. The durable antimicrobial effect observed makes the long-term applications in practical settings feasible, thus promoting sustainability and reducing dependence on synthetic antimicrobial agents with potential ecological impacts. The outcomes of this research go beyond dyeing techniques for textiles and provide ways for the creation of antimicrobial textiles in different sectors such as healthcare, apparel, and home textiles. Through the use of natural colourants and mordants like Lotus seed-based colour and chitosan, textile manufacturers can improve the products' performance while reducing environmental impact. In the future, research may be concentrated on the optimization of the treatment parameters, the discovery of other applications, and the evaluation of the scalability of production processes to achieve the maximum potential of natural colourants and mordants in textile engineering.

Author Contributions

Conceptualization – Rani J, Guru R, Singh J and Santhanam S; methodology – Rani J and Guru R; formal analysis – Rani J and Guru R; investigation – Rani J and Guru R; resources – Rani J, Singh J and Guru R; writing-original draft preparation – Rani J, Guru R and Santhanam S; writing-review and editing – Rani J, Guru R, Singh J and Santhanam S; visualization – Rani J, Singh J and Guru R; supervision – Guru R and Santhanam S. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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