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Applying Giloy Stems Dye to Silk and Lyocell Fabrics to Improve Their Antimicrobial and Fastness Properties Using Bio-Mordant

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Article

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ABSTRACT

The investigation of novel strategies to combat harmful bacteria is warranted given the serious threat that antimicrobial resistance poses to world health. Out of all of these, treating textile materials with antimicrobial compounds has attracted a lot of attention due to its potential to stop the spread of infectious diseases. The goal of this study was to evaluate how silk and lyocell materials' inherent antibacterial qualities might be improved by giloy *dyeing and lemon mordanting. The goal of mordanting was to improve dye adhesion by using only natural ingredients such as citrus lemon extract. Using dye from Azadirachta indica, which was made by aqueous boiling, Lyocell and Silk materials were dyed under various circumstances. Following Giloy dyeing and Lemon mordanting, the antibacterial efficiency significantly improved, notably against common infections like Klebsiella pneumoniae and Staphylococcus aureus, according to the results. Furthermore, the study assessed washing and perspiration fastness capabilities, which yielded positive results and confirmed the method's feasibility. This method has the potential to considerably improve infection control measures in textiles, particularly in fields focused on public health and cleanliness. Given the serious issue of antimicrobial resistance, adopting new textile treatments like this can help to build effective and sustainable solutions. Future studies can investigate further uses and adjustments, assuring its adaptability and wider adoption across many environments.*

KEYWORDS

giloy, dye, silk, lyocell, antimicrobial, bio-mordant, fastness properties

INTRODUCTION

The rise of environmentally friendly dyes is due to the rapidly increasing need for non-cancerogenic and nontoxic dyes in health-sensitive activities such as food colouration and fabric dyeing. For the aforementioned applications, more recently, dyes sourced from nature have become a viable option compared to precarious synthetically produced dyes as they provide the possibility of efficient extraction methodologies [1-3]. The dyeing process is fundamental in the making of attires. Colouration is the most important feature that influences a consumer's decision. A product is purchased because the colour of the garment is appealing to the customer. Water dissolves most natural dyes: hence the aqueous method is preferred to dye clothes [4].

Typically, natural dyes are applied in aqueous solutions, and to ensure the dye's stability on the fibre, a mordant may be necessary. Mordants play a crucial role in the natural dyeing process by enhancing colour uniformity, durability, and adherence of natural dyes to the fabric. Among the commonly used mordants are copper sulfate, chromium, ferrous sulfate, and stannous chloride. These metal-salt-based mordants promote a strong binding between the dye and the fabric, which improves the dye's fastness properties [5]. Indeed, "mordant" is derived from the French word "mord". In the textile industry, both natural and chemical mordants are used to increase the colourfastness of fabrics [6]. Mordants serve an important function in dye absorption and fixing into the fibre, limiting bleeding and fading. When materials are dyed with natural and artificial mordants, they can produce different colours within the same colour range [7].

The plant Giloy, scientifically termed *Tinospora cordifolia*, boasts profound significance in Ayurvedic medicine due to its myriad traditional medicinal applications. Renowned for its anti-diabetic, anti-inflammatory, and anti-cancer attributes [8], Giloy stands out as a multifaceted herb, offering therapeutic advantages such as anti-ulcer, anti-allergic, and anti-AIDS properties. Furthermore, its immune-enhancing prowess has gained recognition, particularly amidst the backdrop of the COVID-19 pandemic [9].

The plant's extensive utilization in diverse medicinal systems underscores its pivotal role in fostering health and combatting numerous diseases through its array of pharmacological actions. Giloy, scientifically known as *Tinospora cordifolia*, harbours a wealth of bioactive compounds including alkaloids, diterpenoid lactones, glycosides, steroids, sesquiterpenoids, and phenolics, as elucidated in numerous research studies [10]. These compounds collectively bestow upon Giloy a spectrum of medicinal attributes, rendering it anti-diabetic, antipyretic, anti-inflammatory, antioxidant, hepato-protective, and immuno-modulatory. Giloy's phytochemical composition, encompassing steroids, alkaloids, diterpenoid lactones, and glycosides, underpins its antioxidant, anti-inflammatory, and cytotoxic actions [11].

Table 1. Presented are the aggregated findings from studies on the dyeing of *Tinospora cordifolia*

Author Name	Practical Implications	Results	Conclusions
Royani A *et al.* [25]	*Tinospora cordifolia* extracts can be eco-friendly antibacterial material. Potential for material protection against *P. aeruginosa* in marine environments.	*Tinospora cordifolia* extracts have antibacterial activity against *P. aeruginosa*. The minimum inhibitory concentration (MIC) was found at 4096 µg/mL.	*Tinospora cordifolia* extracts have antibacterial activity against *P. aeruginosa*. The active compounds in the extracts are phenolic alkaloid derivatives.
Kaur H *et al.* [26]	Green TiO2 nano-cubes degrade textile dye efficiently. Cost-effective, eco-friendly synthesis method for highly efficient photocatalysts.	TiO2 nano-cubes synthesized with *Tinospora cordifolia* biomolecules. 93.4% textile dye degradation under short UV-light irradiation.	TiO2 nano-cubes with *Tinospora cordifolia* show high photocatalytic activity. The green synthesis method is simple, low-cost, and eco-friendly.
Rushikesh S. *et al.* [27]	Nutraceuticals from Tinospora as an alternative to synthetic drugs. Potential for new disease eradication formulations from Tinospora.	*Tinospora cordifolia* has medicinal properties used in traditional medicine. Active components researched for disease control and new formulations.	*Tinospora cordifolia* is a versatile medicinal plant with many uses. The paper highlights its ethnobotanical, pharmacological, and clinical reports.
Gollapudi VR *et al.* [28]	Medical applications: hospital bed materials, aprons Packing applications: due to good antibacterial properties.	AgNPs on cotton fabrics with good antibacterial activity, stable up to 399°C NCCFs are suitable for medical and packing applications due to their properties.	AgNPs on cotton fabrics show antibacterial activity against G+ve and G−ve bacteria. NCCFs can be used for medical and packing applications.

Furthermore, the abundance of key polyphenols such as malic acid, catechin, and quercitrin in Giloy augments its health-promoting effects and chemical resilience, thereby amplifying its potential as a wellspring of bioactive compounds with profound medicinal properties [12].

Utilizing *Tinospora cordifolia* as a natural textile dye holds substantial promise for enhancing fabric quality and longevity. The plant extract's rich composition of bioactive compounds like alkaloids, phenolics, and flavonoids can imbue the fabric with antimicrobial properties, bolstering its resistance to microbial degradation [13]. Furthermore, when *Tinospora cordifolia* biomolecules are employed to encapsulate nano-sized cubes of TiO2, the resultant fabric exhibits heightened photocatalytic activity, reinforcing its durability and resilience against degradation over time. Additionally, studies indicate that *Tinospora cordifolia* extract serves as an effective corrosion inhibitor for metals, suggesting its potential to shield fabrics from corrosion-induced deterioration. In summary, integrating *Tinospora* *cordifolia* into textile dyeing processes not only elevates fabric quality but also confers increased durability and protection against various forms of degradation [14].

Lemon serves as a bio-mordant in dyeing processes through diverse mechanisms, contributing to environmentally friendly textile dyeing practices. Natural mordants derived from lemon play a vital role in augmenting the overall dye uptake into the fabric's innermost fibres, resulting in intensified colour depth compared to chemical counterparts. Utilizing lemon as a bio-mordant fosters eco-conscious dyeing by facilitating interactions like electrostatic attraction, cationic exchange, and hydrogen bonding during the dye adsorption phase [15]. Studies reveal that natural mordants, such as lemon, surpass their chemical counterparts in bolstering the colour intensity and fastness properties of dyed fabrics. Furthermore, employing lemon as a bio-mordant is associated with remarkable visual uniformity, moisture absorption, and antioxidant capabilities in dyed textiles, underscoring its positive influence on the overall quality and sustainability of textile dyeing processes [16]. Lemon peel extract, abundant in essential oils and flavonoids, has proven effective in enhancing the antimicrobial properties of cotton fabrics when applied as a finishing agent. Furthermore, pairing lemon as a bio-mordant with turmeric extract during the dyeing of viscose garments has shown remarkable improvements in colour intensity and fastness characteristics, offering a pathway towards more environmentally friendly textile dyeing methods. Additionally, combining lemon as a bio-mordant with iron post-mordanting has been demonstrated to optimize dye absorption and elevate antimicrobial efficacy against bacteria such as *Staphylococcus aureus* in dyed silk fabrics [17].

In recent times, there has been a notable uptick in the demand for natural dyes, propelled by mounting concerns regarding the environmental repercussions associated with synthetic counterparts. The detrimental impact of synthetic dyes on our ecosystem underscores the pressing need to embrace eco-conscious alternatives. Natural dyes not only provide a sustainable remedy but also encompass a spectrum of functional attributes [18-20].

In this investigation, the leaves of the Giloy plant were used for dyeing purposes. Giloy, known for its environmental benefits and versatile properties, stands out as an excellent source of natural dye. To improve the colourfastness of textiles, a bio-mordant derived from lemon was introduced. Lemon has strong mordanting capabilities along with various functional attributes. The experimental approach involved using silk and lyocell fabrics. While extensive research has focused on cellulose-based fabrics like lyocell, there is a notable lack of studies on protein-based and semi-synthetic textiles. This study aims to bridge this gap by exploring the dyeing potential and performance of Giloy-derived dyes and lemon-based bio-mordant on these less-explored fabric types. Through this exploration, we aim to provide valuable insights into sustainable textile dyeing practices and expand the understanding of natural dye applications across diverse fabric substrates. Many studies have shown that natural dyes often lack good colourfastness properties. However, in this research, I aim to achieve improved fastness properties. Although numerous chemical mordants are available in the market at low prices, they are highly detrimental to the environment. My goal is to use only natural mordants. For this research, I chose lemon as the mordant because few studies have been conducted on lemon as a mordant, and it is easily available. Using lemon not only serves as a mordant but also acts as an antimicrobial agent.

EXPERIMENTAL

Materials and Methods

Material

This study employed dried Giloy leaves to dye silk and lyocell fabric. The Giloy leaves were sourced from the lovely professional university campus, while the silk and lyocell fabric was obtained from the local market in Jalandhar. Lemons were purchased from the Phagwara local market.

Extraction method

The colour was extracted from *Tinospora cordifolia*'s dried stem powder using an aqueous extraction procedure known as boiling. Initially, 300 mL of water was poured into a beaker and heated on a heating plate at a temperature ranging from 60 to 80 °C. Once the temperature reached 60 °C, the dye was added to the water bath. The solution was then heated until its volume was reduced to 200 ml. Subsequently, the boiling solution underwent filtration twice using filter paper to remove any impurities. The resulting dye solution is now ready for application onto the textile for dyeing [21,24]. The dyeing factors are shown in Table 2.

Table 2. Dyeing factors of samples

Dyeing factor	Lowest value	Middle value	High Value
Dye Cons.	10	10	10
Time	45	55	65
Temperature	60	70	80

Colour Fastness Assessment

The dyed fabric's colourfastness was evaluated for washing and perspiration according to particular standards: ISO 105-C06:2010 (B1M) for washing fastness and ISO 105-E04 for perspiration fastness. Additionally, rubbing fastness was evaluated. Colour change rates were observed and scored on a scale from 1 (very poor) to 5 (excellent) to gauge the fabric's performance in terms of colour retention after exposure to washing, perspiration, and rubbing [23].

AATCC 100 - 2019 Standard

The antibacterial activity will be determined using the standard method AATCC 100. The purpose of this assessment is to determine the efficacy of the samples against common bacteria such as S. aureus (gram-positive) and E. coli (gram-negative) using the AATCC 100 test procedure. A comparison analysis will be performed on the leaves of the Giloy tree plant to establish the extent of their antibacterial activities against these prevalent bacteria. Before examination, the samples will be treated with chemical and natural mordants, including lemon juice. Lemon mordants have significant antibacterial activity against microorganisms.

The reduction percentage of bacteria will be calculated, as will the number of colony-forming units (CFU). This computation can be done using the following formula:

$$\text{Bacteria reduction percentage } = \frac{\text{B}-\text{A}}{\text{B}} \times 100 \qquad (1)$$

A quantifies the bacterial-producing units, whereas B represents the bacteria recovered from the treated sample.

Dye Uptake

The dye uptake percentage test is important in several industries, including textiles, medicines, and materials research. It is a fundamental approach for measuring substrate absorbency and material properties. This process involves immersing a sample in a dye solution for a set time to allow for diffusion and absorption. The absorbed dye percentage is then calculated using a specified formula:

$$\%\text{ Dye uptake } = \frac{\text{Absorbance before dyeing} - \text{Absorbance after dyeing}}{\text{Absorbance before dyeing}} \times 100 \qquad (2)$$

The use of a colourimeter allowed for the measurement of pre- and post-dye absorption in silk and lyocell materials, providing useful insights into the integration of dye solutions during textile dying methods. This comprehensive approach broadened our understanding of complex material characteristics and their behaviours under certain conditions.

RESULTS AND DISCUSSION

The experimental investigation produced insightful findings regarding the colour fastness properties of silk and Lyocell fabrics. Washing fastness tests revealed varying degrees of colour retention after laundering, indicating the fabrics' abilities 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 fabrics' colours under simulated wear conditions. Additionally, the assessment of perspiration fastness unveiled the fabrics' resilience to acidic and alkaline perspiration, offering valuable insights into their colourfastness in real-world usage scenarios. Furthermore, examination of antibacterial properties indicated the effectiveness of textile treatments in reducing bacterial populations upon exposure, highlighting the potential of such treatments in enhancing textile hygiene. The sample coding is shown in Table 3.

Table 3. Samples dyeing different conditions.

Sample code	Dye Concertation (g)	Time (Minutes)	Temperature (°C)
S1	10	45	60
S2	10	45	70
S3	10	45	80
S4	10	55	60
S5	10	55	70
S6	10	55	80
S7	10	65	60
S8	10	65	70
S9	10	65	80

The influence of Giloy *dyeing and lemon mordanting on the antimicrobial efficacy of Silk fabric*

The examination into the influence of Giloy dyeing and lemon mordanting on the antimicrobial efficiency of Silk fabric yielded impressive results, notably in terms of *Staphylococcus aureus* inhibition. The experimental technique involved treating silk cloth to these treatments and evaluating their effectiveness against this bacterial strain. The results, displayed in the accompanying table, showed distinct percentages of *Staphylococcus aureus* inhibition linked with different treatment parameters, such as temperature, duration, and dye concentration.

When preserved at 60 °C temperature, the treated silk fabric showed inhibition percentages ranging from 37.70% to 41.90% over various time intervals ranging from 45 to 65 minutes, while maintaining a constant dye concentration of 10 g. As the temperature increased to 70 °C and then to 80 °C, the inhibition of *Staphylococcus aureus* increased significantly. The silk fabric had the highest level of inhibition against *Staphylococcus aureus* at 80 °C for 65 minutes, with a significant percentage of 48.42%.

These findings reveal an unambiguous connection between higher temperatures and longer treatment times, resulting in increased effectiveness in suppressing the growth of *Staphylococcus aureus* on silk fabrics. This suggests that the combination of Giloy dyeing and lemon mordanting, particularly at elevated temperatures and extended exposure times, significantly improved the fabric's ability to combat *Staphylococcus aureus*, potentially augmenting its antimicrobial properties in specific environmental or application contexts. At a temperature of 60 °C, the dyed silk fabric showed inhibition percentages that ranged from 32.92% to 45.56% during time intervals of 45 to 65 minutes, while keeping a constant dye concentration of 10 g. As the temperature rose to 70 °C and then 80 °C, the inhibition of *Klebsiella pneumoniae* increased significantly. Specifically, at 80 °C for 65 minutes, the silk fabric displayed the highest level of inhibition against *Klebsiella pneumoniae*, reaching a significant percentage of 45.56%.

The results presented indicate an obvious connection between higher temperatures and longer treatment times, resulting in increased effectiveness in preventing the growth of *Klebsiella pneumoniae* on silk fabrics. As a result, the combined application of Giloy dyeing and lemon mordanting, especially at high temperatures and long exposure durations, significantly improved the fabric's ability to resist Klebsiella pneumoniae. This implies a possible increase of the fabric's antimicrobial capabilities under specific treatment settings, providing useful insights for applications where protection against *Klebsiella pneumoniae* is paramount.

The inhibition percentages of Staphylococcus aureus and *Klebsiella pneumoniae* on silk fabric treated with Giloy dyeing and lemon mordanting give significant insights into antimicrobial efficiency against these unique bacterial strains.

The inhibition percentages show that *Staphylococcus aureus* is generally more susceptible to the treatment than *Klebsiella pneumoniae* across varied temperature, duration, and dye concentration scenarios. At lower temperatures (60 °C) and shorter durations, *Staphylococcus aureus* inhibition percentages consistently exceeded those of Klebsiella pneumoniae. However, as the temperature rose to 70 °C and then to 80 °C, both bacterial strains showed higher inhibition percentages. Nonetheless, *Staphylococcus aureus* repeatedly showed stronger resistance to the treatment than *Klebsiella pneumoniae* under equal conditions.

At the most significant temperature and duration tested (80 °C for 65 minutes), both *Staphylococcus aureus* and *Klebsiella pneumoniae* had the highest inhibition percentage. *Staphylococcus aureus* had an inhibition rate of 48.43%, whereas *Klebsiella pneumoniae* showed a little lower inhibition percentage of 45.56%. The findings are summarized in Table 4.

Table 4. Results on the antimicrobial effectiveness of Silk fabric

Samples coding No.	Dye concertation (g)	Time (min)	Temperature (°C)	*Staphylococcus aureus* (%)	*Klebsiella pneumoniae* (%)
S1	10	45	60	37.70	33.59
S2	10	45	70	36.76	32.92
S3	10	45	80	41.90	38.79
S4	10	55	60	42.78	40.38
S5	10	55	70	42.43	40.35

Samples coding No.	Dye concertation (g)	Time (min)	Temperature (°C)	*Staphylococcus aureus* (%)	*Klebsiella pneumoniae* (%)
S6	10	55	80	45.07	42.04
S7	10	65	60	46.27	43.08
S8	10	65	70	44.68	41.54
S9	10	65	80	48.43	45.56

The effect of Giloy *dyeing and lemon mordanting on the antimicrobial efficacy of Lyocell fabric*

The investigation into the effectiveness of Lyocell cloth treated with Giloy dyeing and lemon mordanting against *Staphylococcus aureus* provided some intriguing results. The study found distinct patterns in how efficiently it suppresses the growth of *Staphylococcus aureus*. When the temperature was lower, at 60 °C, the fabric's antimicrobial activity steadily rose with exposure time. For example, at 45, 55, and 65 minutes, the inhibition percentages were 34.45%, 37.78%, and 41.47%. When the temperature was raised to 70 °C and 80 °C, the cloth demonstrated significantly greater inhibition of *Staphylococcus aureus*, with inhibition percentages ranging from 42.23% to 47.26%. Notably, the highest inhibition (47.26%) was obtained at 80 °C for 65 minutes with a dye concentration of 10 g. These findings demonstrate how temperature, duration, and dye concentration can considerably improve the antibacterial characteristics of Lyocell fabric through Giloy dyeing and lemon mordanting, notably against *Staphylococcus aureus*.

Some significant results were obtained from the study of the inhibitory percentages of *Klebsiella pneumoniae* on Lyocell fabric treated with lemon mordant and Giloy dye. There were distinct patterns in the suppression of *Klebsiella pneumoniae* under different experimental settings. The cloth demonstrated a progressive rise in antibacterial efficacy as exposure times increased at a lower temperature of 60 °C. Specifically, after 45, 55, and 65 minutes, respectively, inhibition percentages of 31.02%, 34.71%, and 36.34% were noted. The material demonstrated increased inhibition against *Klebsiella pneumoniae* when heated to 70 °C and 80 °C. The percentages of inhibition varied between 39.18% and 43.56% at these high temperatures. Remarkably, the greatest inhibition—which reached 43.56%—was noted after 65 minutes at 80 °C and 10 g of dye. These results demonstrate how temperature, time, and dye concentration affect Lyocell fabric's ability to resist microbes through lemon mordanting and Giloy dyeing, especially when it comes to Klebsiella pneumoniae.

Clear trends in the antibacterial efficiency against these two bacteria were observed when *Staphylococcus aureus* (%) and *Klebsiella pneumoniae* (%) were assessed on Lyocell cloth treated with Giloy dyeing and lemon mordanting.

The fabric has continuously shown rising inhibitory percentages for *Staphylococcus aureus* at higher temperatures and longer dyeing times. Inhibition increased from 34.45% to 41.47% at 60 °C throughout a 45–65 minute duration. Inhibition percentages were further boosted at elevated temperatures of 70 °C and 80 °C, ranging from 42.23% to 47.26%. Remarkably, the maximum inhibition measured was 47.26% at a dye concentration of 10 g and 65 minutes at 80 °C. Conversely, the inhibition of *Klebsiella pneumoniae* exhibited comparable patterns, but at marginally lower percentages in contrast to *Staphylococcus aureus*. Inhibition varied between 31.02% and 36.34% at 60 °C during increasing time intervals of 45 to 65 minutes. At elevated temperatures of 70 °C and 80 °C, the percentage of inhibition changed from 39.18% to 43.56%. The maximum inhibition of 43.56% for *Klebsiella pneumoniae* was likewise obtained at 80 °C for 65 minutes, with a dye concentration of 10 g.

In contrast, under every experimental context, *Staphylococcus aureus* continuously exhibited greater inhibition percentages than Klebsiella pneumoniae. The maximum inhibition values obtained under the identical conditions of 80 °C for 65 minutes with a dye concentration of 10 g for both bacteria were astonishingly comparable, at 47.26% for *Staphylococcus aureus* and 43.56% for Klebsiella pneumoniae. These findings imply that, although both bacteria showed increased inhibition with increasing temperature and duration, *Staphylococcus aureus* was more susceptible than *Klebsiella pneumoniae* to the antimicrobial effects of Giloy dyeing and lemon mordanting on Lyocell fabric. Table 5 presents the results.

Table 5. Results on the antimicrobial effectiveness of Lyocell fabric

Samples coding No.	Temperature (°C)	Time (min)	Dye concertation (g)	*Staphylococcus aureus* (%)	*Klebsiella pneumoniae* (%)
S1	60	45	10	34.45	31.02
S2	70	45	10	37.78	34.71
S3	80	45	10	41.47	36.34
S4	60	55	10	42.23	39.18
S5	70	55	10	41.67	39.46
S6	80	55	10	44.08	41.88
S7	60	65	10	46.77	42.90
S8	70	65	10	45.68	42.56
S9	80	65	10	47.26	43.56

Washing fastness

The findings of this thorough analysis demonstrate how significant a function citrus limon mordant plays in considerably enhancing the washing fastness of silk and Lyocell materials. In addition to the mordant, the combination of temperature and time proved to be essential in improving the materials' ability to be washed quickly. Notably, the comprehensive results shown in Table 6 show that the use of citrus limon mordant significantly improves the washing fastness of silk and Lyocell. The study highlights that to maximize the washing fastness of silk and Lyocell materials, mordanting is a crucial method. The citrus-lemon mordant demonstrated remarkable washing fastness for both kinds of textiles. With meticulously calibrated time and temperature parameters, the meta-mordanting method resulted in notable improvements in the washing fastness of silk and Lyocell materials. Not only were remarkable outcomes at higher dying times and temperatures attained but shorter times and lower temperatures were also attained, demonstrating the approach's adaptability for both types of fabric.

Table 6. Shown the results of washing fastness of Silk and Lyocell fabric

Samples coding No.	Lyocell Fabric	Silk Fabric
S1	4	4.5
S2	4.5	5
S3	4.5	4.5
S4	4.5	5
S5	5	5
S6	5	5
S7	5	5
S8	5	5
S9	5	5

Results shown in table 4 in Garde (1 to 5 G)

Perspiration Fastness

The study uncovered a significant enhancement in the sweat resistance of Lyocell fabric, attributing this improvement to variations in time, temperature, and the addition of mordants during the dyeing process. Higher dyeing times and higher temperatures were shown to be important variables that positively influenced the fabric's resistance to perspiration. The significant improvement in Lyocell fabric's acidic sweat resistance following the addition of citrus limon mordants was especially noticeable. Comparable patterns were seen in silk fabric, which showed perspiration resistance comparable to that of Lyocell. It's interesting to note that silk fabric showed somewhat better sweat resistance than Lyocell, indicating that other variables like temperature, duration, and the use of a mordant during dyeing may also have an impact on silk fabric's sweat resistance. Table 7 presents the Perspiration Fastness findings.

Table 7. Shown the results of Perspiration Fastness of Silk and Lyocell fabric

Samples coding No.	Lyocell Fabric	Silk Fabric
S1	4.5	5
S2	4.5	4.5
S3	4	5
S4	4.5	5
S5	4.5	4.5

Samples coding No.	Lyocell Fabric	Silk Fabric
S6	4.5	5
S7	4.5	4.5
S8	4.5	5
S9	4.5	5

Results shown in table 4 in Garde (1 to 5 G)

Rubbing fastnesses

The rubbing fastness properties of Silk and Lyocell fabric were assessed in-depth using a wide range of studies. The fabric was dyed with a natural colour taken from Giloy and enhanced with Lemon for improved dyeability. Nine fabric samples labelled S1 to S9, underwent varying dye concentrations, time durations, and temperatures to assess their rubbing fastness performance.

In the wet rubbing test without mordanting, results ranged from grade 2 to 3, indicating moderate to good resistance to rubbing. However, with the introduction of mordants, a notable enhancement in wet rubbing fastness was observed, with most samples achieving grades 4 to 5, indicating excellent resistance to wet rubbing.

Similarly, in the dry rubbing test without mordanting, samples exhibited fair to good rubbing fastness, ranging from grade 2 to 3. Yet, post-mordanting, there was a significant improvement in dry rubbing fastness, with most samples achieving grades 4 to 5, signifying excellent resistance to dry rubbing. Furthermore, longer dyeing times and higher temperatures tended to bolster rubbing fastness, as evidenced by the higher grades attained in samples subjected to prolonged dyeing times and elevated temperatures.

Table 8. Shown the results of wet and dry rubbing fastness properties

Samples coding No.	Lyocell Fabric (Dry)	Silk Fabric (Dry)	Lyocell Fabric (Wet)	Silk Fabric (Wet)
S1	4.5	5	2.5	2.5
S2	4.5	4.5	3	3
S3	4	5	3.5	3.5
S4	4.5	5	3	3
S5	4.5	4.5	3.5	4
S6	4.5	5	3.5	3
S7	4.5	4.5	3.5	3.5
S8	4.5	5	4	4
S9	4.5	5	4	4

Results shown in table 4 in Garde (1 to 5 G)

This study examines the complex interactions between temperature, time, and dye concentration to increase the antimicrobial properties of cotton fabric that has been dyed with a natural colour derived from giloy stems and lemon as a mordant to improve dyeability. Through meticulous experimentation, variations in dye concentration (g), time (minutes), and temperature (°C) are systematically explored to gauge their impact on the ultimate antimicrobial efficacy of the treated fabric.

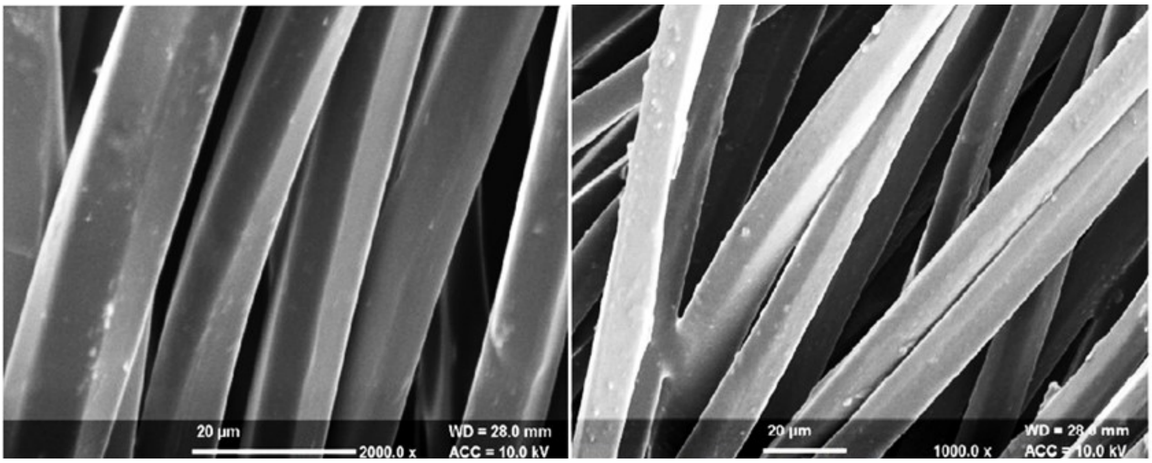
The research aims to pinpoint the most effective dyeing conditions by precisely optimizing these parameters, thereby maximizing the antimicrobial properties of the fabric. Utilizing the natural colour derived from Gilot Stem and Lemon as a mordant embodies a sustainable approach to bolstering the functional properties of textiles.

Such investigations hold promise for a multitude of applications across diverse fields such as healthcare, apparel, and beyond, where antimicrobial textiles play a pivotal role in safeguarding against microbial threats and promoting hygiene. By offering insights into the intricacies of the dyeing process, this study constitutes a significant stride towards advancing textile technology and furnishing novel solutions for industries reliant on antimicrobial textiles.

Field Emission Scanning Electron Microscopy

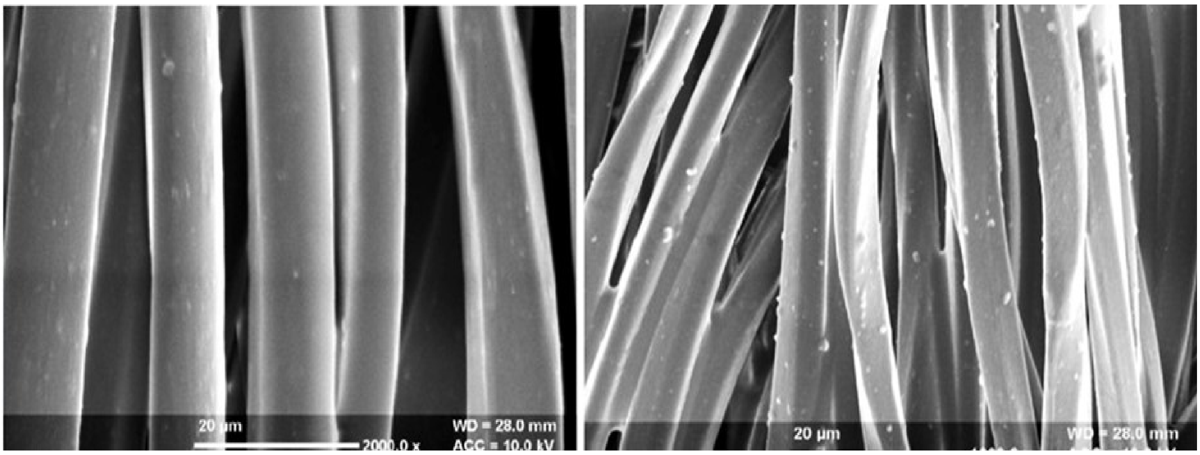
Field Emission Scanning Electron Microscopy (SEM) stands as a cutting-edge imaging technique utilized to scrutinize the surface morphology and structure of materials with unparalleled precision. Through the utilization of a stream of electrons, it produces high-resolution images that provide intricate insights into the sample's surface topography.

Analysis of SEM images has unveiled the remarkable antimicrobial effectiveness of Gilot Stem, coupled with the consistent application of uniformity onto the fabric surface. Figures 1 and 2 present compelling evidence, distinctly illustrating the contrast between surfaces treated with and without the mordant.



a) b)

Figure 1. Images of FeSem showing silk fabric a) without and b) with mordanting



a) b)

Figure 2. Images of FeSem showing Lyocell fabric a) without and b) with mordanting

Dye Uptake

The findings from the dye uptake experiments offer intriguing insights into the affinity of various fabrics for dyes, as well as the influence of specific treatment approaches. In a dye uptake of 121.19 mg/g, dyed silk fabric showed a moderate affinity for the dye. In contrast, Meta mordanting with C.L. (Silk Fabric) significantly boosted the dye uptake to 155.27 mg/g, highlighting the substantial enhancement in the fabric's dye absorption capacity through this treatment method.

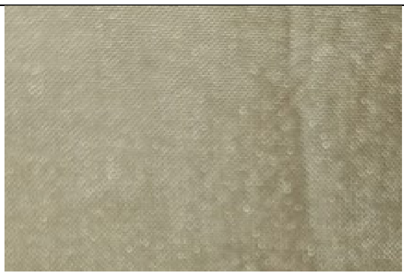
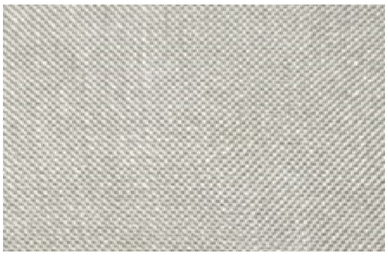
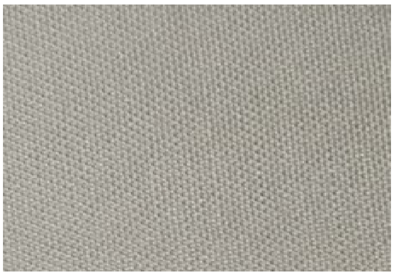
Table 9. Show the dye uptake of Silk and Lyocell fabric

S. No.	Fabric	Fabric weight (g)	Dye uptake (mg/g)
1	Dyed Silk Fabric	5	121.19
2	Meta mordanting with C.L. (Silk Fabric)	5	155.27
4	Dyed Lyocell Fabric	5	116.12
5	Meta mordanting with C.L. (Lyocell Fabric)	5	134.23

Similarly, Dyed Lyocell Fabric exhibited a dye uptake of 116.12 mg/g, suggesting a reasonable affinity for the dye. On the other hand, a significantly greater dye absorption of 134.23 mg/g was obtained after meta-mordanting with C.L. (Lyocell Fabric), demonstrating the efficacy of this treatment technique in improving the fabric's dye-absorbing capacity. Outcomes are displayed in Table 9.

These results underscore the significance of both fabric type and treatment methods in determining dye uptake, providing valuable insights for optimizing dyeing processes in the textile industry.

Table 10. Presented the dyed and undyed fabrics

Fabric	Lemon mordanting fabric	Undyed samples
Silk		
Lyocell		

CONCLUSION

The investigation into how the antibacterial properties of silk and lyocell fabric were affected by giloy dyeing and lemon mordanting produced encouraging results about these materials' potential as agents against diseases such as *Klebsiella pneumoniae* and *Staphylococcus aureus*. Silk and lyocell fabric treated with giloy dyeing and lemon mordanting processes showed strong antibacterial capabilities against both bacterial strains. Differences in time, temperature, and uniform dye concentration significantly affected the treated fabric's antibacterial effectiveness against these bacteria.

The amalgamation of lemon mordanting with giloy dyeing emerged as a prospective avenue for enhancing the antimicrobial characteristics of textile materials, particularly lyocell and silk fabrics, rendering them more suitable for applications necessitating antimicrobial capabilities. This methodology, contingent upon multifarious factors, holds promise for the textile industry in its pursuit of fabricating materials endowed with augmented antimicrobial attributes for diverse applications ranging from everyday attire to healthcare settings.

Further refinement through additional investigation and parameter optimization may engender more potent antimicrobial treatments for textiles. This comprehensive analysis elucidates pivotal variables influencing the washing, perspiration, and rubbing fastness of lyocell and silk fabrics. The utilization of citrus limon mordant has been instrumental in augmenting the washing fastness of both textiles, showcasing its adaptability across various dyeing scenarios. The study underscores the dynamic interplay between temperature, duration, and fabric properties in enhancing lyocell fabric's resistance to perspiration, with prolonged dyeing periods and heightened temperatures proving beneficial in this regard. Additionally, citrus limon mordants have been shown to bolster the acidic sweat resistance of lyocell fabric, thereby enhancing its overall durability. Analogous trends observed in silk fabric underscore the broad applicability of these findings across diverse fabric types.

For textile practitioners and researchers alike, the insights gleaned from exploring the intricate relationships among mordants, duration, temperature, and fabric characteristics offer invaluable guidance. The implications of this study transcend laboratory confines, furnishing a pathway for strategically enhancing sweat resistance and washing durability in textile manufacturing. These findings may catalyze enhancements that fortify the strength and longevity of silk and lyocell fabrics, aligning with the industry's pursuit of performance-driven, sustainable solutions, thus advancing both material science and textile technology.

Author Contributions

Conceptualization – Rani J, Guru R, Singh J, Fangueiro R, Santhanam S; methodology – Rani J, Guru R, Fangueiro R, Santhanam S and Singh J; formal analysis – Rani J, Guru R, Fangueiro R and Santhanam S; investigation – Rani J, Guru R, Fangueiro R and Santhanam S; resources – Rani J, Guru R and Singh J; writing-original draft preparation – Rani J, Guru R and Singh J; writing-review and editing – Rani J, Guru R and Fangueiro R; visualization – Rani J, Guru R; supervision – Guru R, Singh J, Fangueiro 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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REFERENCES

[1] Bechtold T, Mahmud-Ali A, Mussak R. Natural dyes for textile dyeing: A comparison of methods to assess the quality of Canadian golden rod plant material. Dyes and Pigments. 2007; 75(2):287–93. https://doi.org/10.1016/j.dyepig.2006.06.004

[2] Chakraborty L, Pandit P, Maulik SR. Acacia auriculiformis - A natural dye used for simultaneous coloration and functional finishing on textiles. Journal of Cleaner Production. 2020; 245:118921. https://doi.org/10.1016/j.jclepro.2019.118921

[3] Das SC, Uddin MA. Extraction and Characterization of Antimicrobial surgical Suture from the bast of Tinospora Cordifolia. Journal of Natural Fibers. 2022; 19(15):11235–11245. https://doi.org/10.1080/15440478.2021.2022560

[4] Ebuy W, Jabasingh SA, Demsash HD, Jaya NV, Gebrehiwot G. Eco-friendly cotton fabric dyeing using a green, sustainable natural dye from Gunda Gundo (Citrus sinensis) orange peels. Biomass Conversion and Biorefinery. 2021; 13(6):5219–5234. https://doi.org/10.1007/s13399-021-01550-6

[5] Hosen MdD, Rabbi MdF, Raihan MdA, Mamun MdAA. Effect of turmeric dye and biomordants on knitted cotton fabric coloration: A promising alternative to metallic mordanting. Cleaner Engineering and Technology. 2021; 3:100124. https://doi.org/10.1016/j.clet.2021.100124

[6] Ibrahim NA, El-Gamal AR, Gouda M, Mahrous F. A new approach for natural dyeing and functional finishing of cotton cellulose. Carbohydrate Polymers. 2010; 82(4):1205–1211. https://doi.org/10.1016/j.carbpol.2010.06.054

[7] Janarthanan M, Kumar MS. The properties of bioactive substances obtained from seaweeds and their applications in textile industries. Journal of Industrial Textiles. 2017; 48(1):361–401. https://doi.org/10.1177/1528083717692596

[8] Kamel M, El-Shishtawy RM, Yussef BM, Mashaly H. Ultrasonic assisted dyeing III. Dyeing of wool with lac as a natural dye. Dyes and Pigments. 2005; 65(2):103–110. https://doi.org/10.1016/j.dyepig.2004.06.003

[9] Liu L, Zhang J, Tang R. Adsorption and functional properties of natural lac dye on chitosan fiber. Reactive and Functional Polymers/Reactive & Functional Polymers. 2013; 73(11):1559–1566. https://doi.org/10.1016/j.reactfunctpolym.2013.08.007

[10] Maulik SR, Chakraborty L, Pandit P. Evaluation of Cellulosic and Protein Fibers for Coloring and Functional Finishing Properties Using Simultaneous Method with Eucalyptus Bark Extract as a Natural Dye. Fibers and Polymers. 2021; 22(3):711–9. https://doi.org/10.1007/s12221-021-0092-0

[11] Parvathalu K, Rajitha K, Chandrashekar B, Sathvik KS, Bhasker KP, Sreenivas BS, et al. Biomimetic synthesis of copper nanoparticles using Tinospora cordifolia plant leaf extract for photocatalytic activity applications. Plasmonics. 2023; 19:825-834. https://doi.org/10.1007/s11468-023-02037-y

[12] Pascual G, García-Raurich J, Cañal JML, Riba-Moliner M. Orange-derived and lemon-derived adsorbents with controlled grain for an efficient elimination of some cationic and anionic dyes. Pigment & Resin Technology. 2021; 50(5):475–83. https://doi.org/10.1108/prt-05-2021-0056

[13] Rani S, Chaudhary S. Adsorption of methylene blue and crystal violet dye from waste water using Citrus limetta peel as an adsorbent. Materials Today: Proceedings. 2022; 60:336–44. https://doi.org/10.1016/j.matpr.2022.01.237

[14] Ren Y, Gong J, Wang F, Li Z, Zhang J, Fu R, et al. Effect of dye bath pH on dyeing and functional

properties of wool fabric dyed with tea extract. Dyes and Pigments. 2016; 134:334–41. https://doi.org/10.1016/j.dyepig.2016.07.032

[15] Riaz A, Kalsoom U, Bhatti HN, Jesionowski T, Bilal M. Citrus limon peroxidase-assisted biocatalytic approach for biodegradation of reactive 1847 colfax blue P3R and 621 colfax blue R dyes. Bioprocess and Biosystems Engineering. 2022; 46(3):443–52. https://doi.org/10.1007/s00449-022-02802-z

[16] Safapour S, Rather LJ, Moradnejad J, Mir SS. Functional and Colorful Wool Textiles through Ecological Dyeing with Lemon Balm Bio-Dyes and Mordants. Fibers and Polymers. 2023; 24(12):4357–70. https://doi.org/10.1007/s12221-023-00397-0

[17] Saini R, Kumar P. Green synthesis of TiO2 nanoparticles using Tinospora cordifolia plant extract & its potential application for photocatalysis and antibacterial activity. Inorganic Chemistry Communications/Inorganic Chemistry Communications. 2023; 156:111221. https://doi.org/10.1016/j.inoche.2023.111221

[18] Sharma R, Sharma RA, Singh RR, Kumari A. Evaluation of biogenic zinc oxide nanoparticles from Tinospora cordifolia stem extract for photocatalytic, anti-microbial, and antifungal activities. Materials Chemistry and Physics. 2023; 297:127382. https://doi.org/10.1016/j.matchemphys.2023.127382

[19] Jabar JM, Al-Ahmary KM, Alshdoukhi IF, Alghamdi AA, El-Rayyes A, Alrahili MR. Cashew (Anacardium occidentale L) bark extract for eco-safe dyeing of mordanted cotton fabric: Colorimetric and biomedical functional properties. Sustainable Chemistry and Pharmacy. 2024; 39:101587. https://doi.org/10.1016/j.scp.2024.101587

[20] Jabar JM, Adebayo MA, Oloye MT, Adenrele AY, Oladeji AT. Catechin-rich reddish-brown dye from cocoa (Theobroma cacao L) leaf for functionalizing herbal-anchored wool fabrics. Industrial Crops and Products. 2023; 205:117465. https://doi.org/10.1016/j.indcrop.2023.117465

[21] Thakur N, Kumar A, Thakur N. Tinospora cordifolia and polyvinylpyrrolidone encapsulated dual doped Ni-Cu TiO2 emerging nanocatalyst for the removal of organic dyes from wastewater and its free radical assay activity. Hybrid Advances. 2023; 4:100086. https://doi.org/10.1016/j.hybadv.2023.100086

[22] Thakur N, Thakur N. Removal of organic dyes and free radical assay by encapsulating polyvinylpyrrolidone and Tinospora Cordifolia in dual (Co–Cu) doped TiO2 nanoparticles. Environmental Pollution. 2023; 335:122229. https://doi.org/10.1016/j.envpol.2023.122229

[23] Zhou Y, Zhang J, Tang R, Zhang J. Simultaneous dyeing and functionalization of silk with three natural yellow dyes. Industrial Crops and Products. 2015; 64:224–32. https://doi.org/10.1016/j.indcrop.2014.09.041

[24] Jabar JM, Ogunmokun AI, Taleat TAA. Color and fastness properties of mordanted Bridelia

ferruginea B dyed cellulosic fabric. Fashion and Textiles. 2020; 7:1. https://doi.org/10.1186/s40691-019-0195-z

[25] Royani A, Hanafi M, Julistiono H, Dinoto A, Lotulung PDN, Manaf A. The Potential of Tinospora cordifolia Extracts as Antibacterial Material against Pseudomonas aeruginosa. Trends in Sciences. 2022; 20:3884. https://doi.org/10.48048/tis.2023.3884

[26] Kaur H, Goyal V, Singh J, Kumar S, Rawat M. Biomolecules encapsulated TiO2nano-cubes using Tinospora cordifolia for photo degradation of a textile dye. Micro & Nano Letters. 2019; 14:1229–1232. https://doi.org/10.1049/mnl.2019.0340

[27] Said R, Jadhav SL, Kamble SC. Tinospora cordifolia a Medicinal plant with many roles: A Review. Research Journal of Pharmacognosy and Phytochemistry. 2023; 15(1):87–90. https://doi.org/10.52711/0975-4385.2023.00013

[28] Gollapudi VR, Mallavarapu U, Seetha J, Akepogu P, Amara VR, Natarajan H, Anumakonda V. In situ generation of silver and silver oxide nanoparticles on cotton fabrics using Tinospora cordifolia as bio reductant. SN Applied Sciences. 2020; 2: 508. https://doi.org/10.1007/s42452-020-2331-1