Effect of Vitamin C After-Treatment on the Lightfastness of Ketapang (*Terminalia Catappa*) Dyed Cotton and Silk

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ABSTRACT

Natural dyes are increasingly studied as a more sustainable option for textile colouration. However, poor colourfastness, particularly to light, remains one of their main limitations. This study examined the effect of different alum mordant concentrations and Vitamin C after-treatment on cotton and silk dyed with *Terminalia catappa* (Ketapang) leaf extract. The dye concentration was fixed at 50% weight of fabric (w.o.f.), while alum was applied at 25%, 37.5% and 50% w.o.f. Vitamin C at 1 g/L was applied under three treatment conditions. For AT1 and AT2, Vitamin C was added to the dyebath at 95 °C and 60 °C, respectively, while AT3 involved separate immersion in Vitamin C solution at 23 °C. Samples without Vitamin C after-treatment were used as controls. All samples were exposed to direct sunlight for 40 h, and the colour changes were visually compared. The results showed different responses between silk and cotton. Silk developed deeper shades after sunlight exposure, particularly at the highest mordant concentration. Cotton showed only small colour changes and remained relatively pale under the different treatment conditions. Overall, Vitamin C after-treatment produced a more noticeable colour response on silk than on cotton.

Keywords: *Terminalia catappa*; natural dye; Vitamin C after-treatment; lightfastness; sustainability

INTRODUCTION

Natural dyes are increasingly studied in textile colouration as a more sustainable alternative to synthetic dyes (Sarma et al., 2025). Most natural dyes are obtained from renewable plant sources and may reduce some of the environmental concerns associated with synthetic dyeing. Many plant-based dyes also contain natural compounds that may provide additional properties such as antioxidant, ultraviolet (UV) protection and antimicrobial activities (Mazumder et al., 2026).

Terminalia catappa, commonly known as Ketapang in Malaysia, is widely available in tropical regions and has potential as a natural dye source. Its leaves contain tannins, flavonoids and other polyphenolic compounds that contribute to colour development and antioxidant properties (Mazumder et al., 2026; Murwanti et al., 2025). These compounds can produce yellow to brown shades, making Ketapang leaves suitable for further study in textile colouration. The performance of natural dyes can be affected by several factors, including mordant concentration, after-treatment condition and textile fibre type. Vitamin C, or ascorbic acid, can be used as an antioxidant after-treatment, while alum is commonly used as a mordant in natural dyeing. Cotton and silk have different fibre structures and dye affinities and may therefore respond differently to the same dyeing and after-treatment conditions. These factors are important when examining the colour behaviour of natural-dyed fabrics during light exposure.

Problem Statement

Despite their environmental advantages, the wider use of natural dyes is still limited by several performance issues, particularly poor colourfastness during light exposure (Mazumder et al., 2026). Plant-based colourants may fade or undergo colour changes when exposed to light, which can affect their suitability for textile applications.

Terminalia catappa has been studied as a natural dye for different textile materials. Previous research has also examined the use of Vitamin C after-treatment on selected natural dyes, including Ketapang on silk (Faiz et al., 2016). However, the effect of different mordant concentrations on the colour response of Vitamin C after-treated Ketapang-dyed fabrics has received less attention. Comparisons between cotton and silk under the same treatment conditions are also limited.

Therefore, this study examines Ketapang-dyed cotton and silk using different alum mordant concentrations and Vitamin C after-treatment conditions. The study focuses on the comparative colour response of both fibres following direct sunlight exposure and provides further information on the influence of mordant concentration and fibre type on the treatment outcome.

Research Objectives

This study aims to:

1. Observe the effect of different alum mordant concentrations on the lightfastness of *Terminalia catappa* (Ketapang) dyed cotton and silk fabrics.

2. Compare the effect of Vitamin C after-treatment on the lightfastness of *Terminalia catappa* (Ketapang) dyed cotton and silk fabrics.

Research Question

How do different alum mordant concentrations and Vitamin C after-treatment affect the lightfastness of *Terminalia catappa* (Ketapang) dyed cotton and silk fabrics?

Significance Of Study

This study provides information on the use of *Terminalia catappa* (Ketapang) as a natural dye for cotton and silk fabrics. It also observes the effects of different alum mordant concentrations and Vitamin C after-treatment on lightfastness. The results help to show how these factors affect the colour response of Ketapang-dyed fabrics after light exposure.

The findings can be used as a reference for further studies on plant-based dyes and sustainable textile dyeing. The study also provides additional information on the use of Ketapang leaves, which are widely available in Malaysia, as a natural dye source for textile applications.

Scope and Limitations of Study

This study focuses on the comparative colour response of *Terminalia catappa* (Ketapang)-dyed cotton and silk fabrics using different alum mordant concentrations and Vitamin C after-treatment conditions. All samples were exposed to direct sunlight for 40 h. The exposure duration followed the manual lightfastness approach previously reported by Faiz et al. (2016).

The colour changes were evaluated by naked-eye observation through visual comparison of the exposed samples with the original, unexposed samples. As natural sunlight is affected by environmental conditions, the findings are interpreted as comparative observations under the conditions of this study rather than standardised lightfastness ratings. Instrumental colour measurement and chemical characterisation of the colour changes were not included within the scope of the present study.

LITERATURE REVIEW

Natural Dyes in Sustainable Textile Colouration

The textile industry is increasingly adopting sustainable dyeing practices due to growing environmental awareness and stricter environmental regulations (Sarma et al., 2025). Synthetic dyes have long been used because they are cost-effective and produce consistent colours (Kumarmath et al., 2022). However, their extensive use has raised environmental and health concerns. Synthetic dye wastewater contains non-biodegradable compounds and hazardous substances, including carcinogenic aromatic amines from azo dyes, which can pollute soil and water resources and cause adverse health effects such as skin allergies (Bukhari et al., 2023; Mazumder et al., 2026; Sarma et al., 2025).

As a more environmentally friendly alternative, natural dyes derived from plant materials have received increasing attention because they are biodegradable, less toxic and may provide additional functional properties, such as ultraviolet (UV) protection and antimicrobial activity (Mazumder et al., 2026; Sarma et al., 2025). However, their wider application remains limited by several challenges, including low dye uptake, weak fibre affinity and poor colourfastness, particularly to washing and light exposure (Bukhari et al., 2023; Krisnawati et al., 2022; Murwanti et al., 2025). Therefore, developing effective and environmentally friendly dyeing formulations remains an important area of research for improving the practical application of natural dyes in the textile industry (Sarma et al., 2025).

Terminalia Catappa (Ketapang) As A Natural Dye Source

Terminalia catappa (Ketapang) leaves contain tannins, flavonoids and other polyphenolic compounds that contribute to their dyeing properties (Annegowda et al., 2010; Mwangi et al., 2024). Tannins are important natural colour compounds and can produce yellowish-brown to dark brown shades on textile fibres (Krisnawati et al., 2022; Murwanti et al., 2025). The colour obtained may vary according to the dyeing and mordanting conditions used.

Besides their colouring properties, Ketapang leaves have also been reported to contain compounds with antioxidant, ultraviolet (UV) protection and antimicrobial properties (Mazumder et al., 2026; Mwangi et al., 2024). These additional properties increase the potential of Ketapang leaves for textile applications, particularly as a plant-based dye source for more sustainable textile colouration.

Dyeing of Cotton and Silk Fabrics Using Natural Dyes

The dyeing performance of natural dyes can vary according to the type and properties of the textile fibre (Sarma et al., 2025). Cotton and silk are natural fibres with different structures and dyeing characteristics, which can result in different levels of dye uptake, colour intensity and colourfastness (Hoang et al., 2017).

Cotton is a cellulosic fibre and generally has lower affinity for many natural dyes, including tannin-based dyes. This may result in lighter colour shades and lower colourfastness when suitable mordants or dyeing methods are not used (Krisnawati et al., 2022; Mazumder et al., 2026). Mordanting is therefore important in supporting the dyeing performance of many plant-based dyes on cotton.

Silk, on the other hand, is a protein fibre and generally has better affinity for many natural dyes (Sarma et al., 2025). Natural colour compounds such as tannins and flavonoids can produce higher dye uptake and deeper shades on silk. Previous studies have also reported better colourfastness on silk for some natural dye systems (Hoang et al., 2017; Mazumder et al., 2026; Vadwala & Kola, 2017). These differences between cotton and silk are important when comparing their response to the same natural dyeing and after-treatment conditions.

Oxidation and Light Exposure of Natural Dyes

Natural colourants may change when exposed to air and light. Oxidation is a common reaction in some plant-based colour compounds. For example, brazilin in Sepang wood / Sappan wood can oxidise to brazilein when exposed to oxygen in the air, which causes a change in colour (Bukhari et al., 2023). This shows that oxidation can occur naturally in plant colourants during normal exposure to air.

Light exposure may also affect the colour stability of natural dyes. Sunlight and ultraviolet (UV) radiation can cause photo-oxidation or changes in the colour compounds, which may result in fading or other colour changes (Mazumder et al., 2026). Oxidation of phenolic compounds has also been reported in *Terminalia catappa* leaves during natural colour development (Mazumder et al., 2026). These findings show that oxidation and light exposure can affect the colour behaviour of plant-based dyes.

Dyeing Formulations, Vitamin C After-Treatment and Lightfastness

Different dyeing formulations and after-treatment methods have been studied to improve the colourfastness of natural dyes (Bukhari et al., 2023; Mazumder et al., 2026). Among the factors that influence the dyeing process, pH plays an important role because it affects the interaction between the dye and textile fibre (Mazumder et al., 2026; Sarma et al., 2025). Acidic dyeing conditions are generally suitable for protein fibres such as silk and can support better dye uptake and colour development (Mazumder et al., 2026). However, many plant-based dyes are sensitive to changes in pH, which may also affect their colour shade and stability (Sarma et al., 2025; Vadwala & Kola, 2017).

Table 1: Summary of previous studies related to natural dyeing, antioxidant treatment and lightfastness.

Author(s)	Antioxidant / Lightfastness Relevance	Method	Findings
Mazumder et al. (2026)	Inherent polyphenolic antioxidants (no additional after-treatment)	Mordant-free dyeing of nylon using *T. catappa* leaf extract	High colour strength, excellent UV protection, good wash, rubbing, saliva and light fastness
Mwangi et al. (2024)	L-Ascorbic acid (Vitamin C) used as antioxidant reference standard	Methanolic and aqueous leaf extracts evaluated for antioxidant activity.	Strong antioxidant activity comparable to the Vitamin C reference, indicating good antioxidant potential.
Annegowda et al. (2010)	Vitamin C equivalent antioxidant capacity (VCEAC)	Hydrolysed and non-hydrolysed leaf extracts evaluated for antioxidant activity.	Non-hydrolysed extracts showed higher antioxidant activity than hydrolysed extracts.
Murwanti et al. (2025)	Inherent tannin-based antioxidants	Batik dyeing using different mordants and dipping cycles.	Ferrous sulfate mordant with four dipping cycles showed the best colour retention.
Sarma et al. (2025)	Inherent UV protection and antioxidant propertie	Natural dyes extracted under different conditions and applied to Eri silk using bio-mordanting	Improved wash and light fastness, with effective UV protection on dyed silk.
Hoang Thi Linh et al. (2017)	Ecological safety and colour stability	Cotton and silk fabrics dyed with *T. catappa* leaf extract and evaluated for ecological properties and colour fastness.	Dyed fabrics were safe for skin contact and showed good washing and perspiration fastness.

Table 1: Summary of previous studies related to natural dyeing, antioxidant treatment and lightfastness.

Author(s)	Antioxidant / Lightfastness Relevance	Method	Findings
Vadwala & Kola (2017)	Sunlight resistance through natural antioxidants and mordanting	Silk fabrics dyed with *T. catappa* leaf extract using different mordants.	Excellent sunlight fastness (Grade 5) and good wash fastness were achieved.
Faiz et al. (2016)	Vitamin C (ascorbic acid) after-treatment	Alum pre-mordanted silk dyed with pulverised natural dyes, treated with Vitamin C and exposed to direct sunlight for 40 h	Vitamin C improved the lightfastness of several natural dyes, although the effect varied according to the dye source

Lin et al. (1997)	Scavenging of ascorbic acid-induced oxidative systems	Antioxidant activity of *T. catappa* leaf extracts evaluated using free radical scavenging assays.	Strong antioxidant activity with inhibition of lipid peroxidation.

After-treatment using UV absorbers and antioxidants has also been studied to improve the lightfastness of natural dyes. Vitamin C, or ascorbic acid, is known for its antioxidant properties and has been used as an after-treatment for naturally dyed textiles. Faiz et al. (2016) applied Vitamin C after-treatment to alum pre-mordanted silk dyed with several pulverised plant dyes and exposed the samples to direct sunlight for 40 h. The results showed that the effect of Vitamin C varied according to the plant dye used. Table 1 summarises previous studies related to natural dyeing, antioxidant treatment and lightfastness.

Previous studies have shown the potential of Vitamin C and other antioxidants in natural dyeing. However, the effect of different alum mordant concentrations together with Vitamin C after-treatment has received less attention. The response may also differ according to fibre type because cotton and silk have different structures and dyeing behaviour. Therefore, the present study compares Ketapang-dyed cotton and silk using different alum mordant concentrations and Vitamin C after-treatment conditions before exposure to direct sunlight.

CONCLUSION AND RESEARCH GAP

Terminalia catappa has been studied as a natural dye for different textile materials, including cotton, silk and nylon. Previous studies have also reported its antioxidant properties and the use of Vitamin C after-treatment on natural-dyed silk fabrics (Annegowda et al., 2010; Faiz et al., 2016; Mazumder et al., 2026; Mwangi et al., 2024). However, less attention has been given to the effect of different alum mordant concentrations on the lightfastness behaviour of Vitamin C after-treated *T. catappa*-dyed fabrics.

Comparisons between cotton and silk under the same dyeing, mordanting and Vitamin C after-treatment conditions are also limited. Therefore, this study focuses on the effect of different alum mordant concentrations and Vitamin C after-treatment on *T. catappa*-dyed cotton and silk following direct sunlight exposure.

Conceptual Framework

Figure 1 presents the conceptual framework of the study. *Terminalia catappa* leaf extract was used to dye cotton and silk fabrics prepared with different alum mordant concentrations. The dyed fabrics were then subjected to Vitamin C after-treatment under different treatment conditions. Treated and untreated samples were exposed to direct sunlight for 40 h, and the colour changes were visually compared.

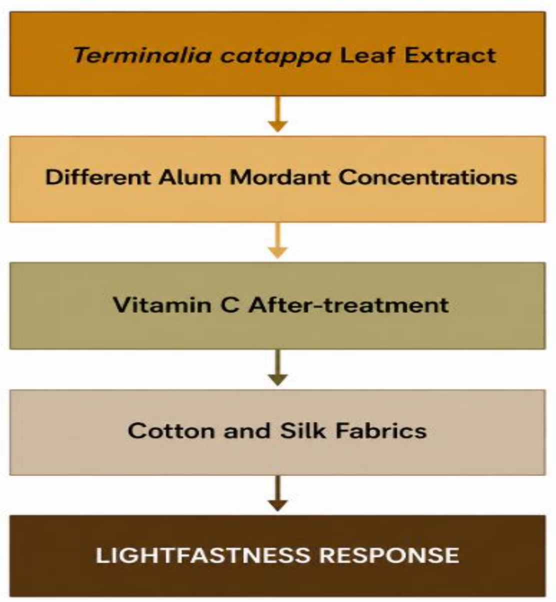


Figure 1: Conceptual framework of the study.

METHODOLOGY

Research Design

This study used an experimental research design involving cotton and silk fabrics dyed with *Terminalia catappa* leaf extract. The dye concentration was kept constant, while the alum mordant concentration and Vitamin C after-treatment condition were varied. Treated and untreated samples were exposed to direct sunlight, and the colour changes were visually compared.

Materials And Chemicals

The materials and chemicals used in this study are summarised in Table 2. Commercial Habutai silk (32 g/m) and mercerised cotton (medium weight) were selected as the textile substrates. Dried *Terminalia catappa* leaves served as the natural dye source; fresh leaves were collected and dried in a laboratory oven at 40 °C prior to extraction. Aluminium ammonium sulphate (alum) was used as the mordant, while reagent-grade Vitamin C (L-ascorbic acid, A7506, ≥99% purity; Sigma-Aldrich, USA) was employed as the after-treatment agent. All chemicals were used as received without further purification.

Table 2: Materials and chemicals used in this study.

Material	Purpose	Specification
Habutai silk	Fabric substrate	Commercial, 32 g/m
Mercerised cotton	Fabric substrate	Commercial, medium weight
Dried *Terminalia catappa* leaves	Natural dye source	Oven-dried at 40 °C
Alum	Mordant	Analytical grade
Vitamin C	After-treatment	Sigma-Aldrich, ≥99% purity

Mordanting and Dyeing

Before the dyeing process, cotton and silk fabrics were pre-mordanted with alum for 60 min at 95 °C. The fabrics were left in the mordant bath and cooled overnight. The treated fabrics were subsequently rinsed with water, air-dried and reserved for the dyeing process.

For dye extraction, the oven-dried *Terminalia catappa* leaf powder was soaked in water for 24 h before being heated for 60 min to facilitate colour extraction. Dyeing was then carried out by immersing the pre-mordanted fabrics in the prepared dyebath at 95 °C for 60 min. After dyeing, the fabrics remained in the dyebath overnight before being rinsed or subjected to the Vitamin C after-treatment.

Table 3: Mordanting and dyeing conditions used in the study.

Parameter	**Condition**
Fabric weight	17.60 g
Pulverised *Terminalia catappa* leaf powder	8.80 g (50% w.o.f.). The fixed dye concentration was selected based on preliminary dyeing trials and was kept constant throughout the study.
Water	1.5 L

Alum mordant concentration	4.40 g (25% w.o.f.), 6.60 g (37.5% w.o.f.) and 8.80 g (50% w.o.f.)
Mordanting temperature	95 °C
Mordanting duration	60 min, followed by overnight cooling
Dye extraction	Leaf powder pre-soaked for 24 h, then heated for 60 min
Dyeing duration	60 min at 95 °C, followed by overnight cooling in the dyebath

Note: w.o.f. = weight of fabric

Vitamin C After-Treatment

Vitamin C after-treatment was applied to the dyed fabric samples using three different conditions, as shown in Table 4. A Vitamin C concentration of 1 g/L distilled water was used for all treatments. AT1 and AT2 were carried out in the dyebath at different temperatures, while AT3 was treated separately in the Vitamin C solution at room temperature. An untreated sample was used as the control for comparison.

Table 4: Vitamin C After-Treatment Condition.

Sample	After-treatment Condition
Control	No Vitamin C after-treatment
AT1	Vitamin C added to dyebath; stirred for 15 min at 95 °C
AT2	Vitamin C added to dyebath; stirred for 15 min at 60 °C
AT3	Immersed in Vitamin C solution for 15 min at 23 °C

Vitamin C concentration: 1 g/L distilled water.

Lightfastness Evaluation

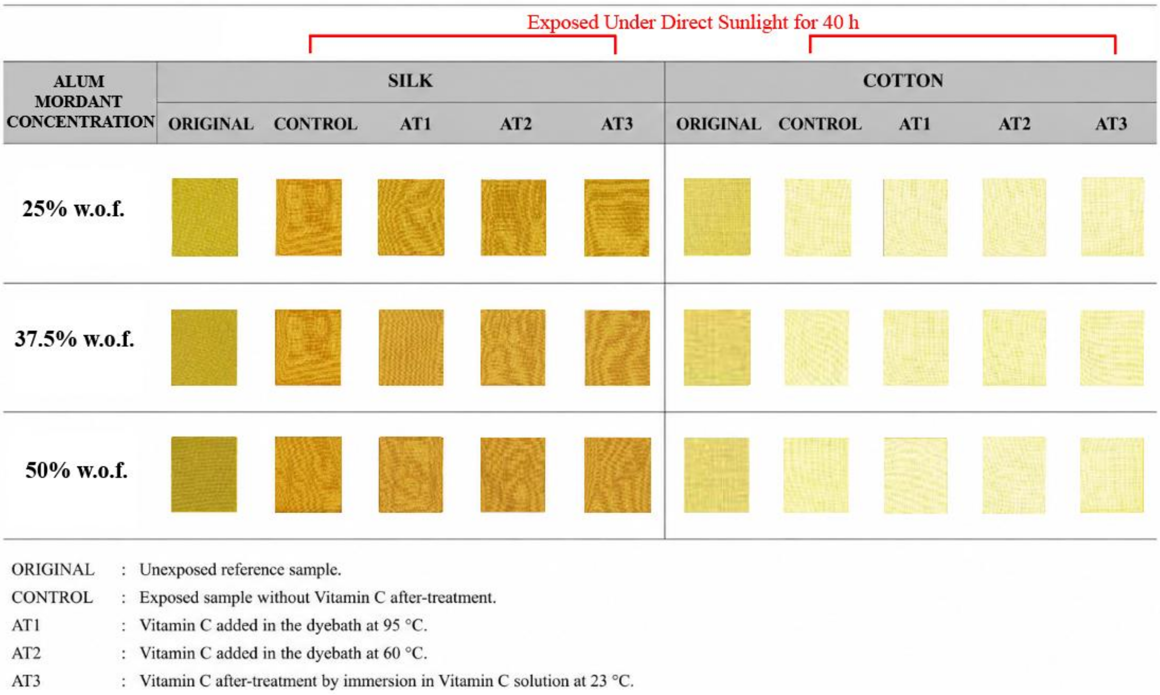
The dyed fabric samples were exposed to direct sunlight for 40 h, following the exposure duration previously reported by Faiz et al. (2016). The exposed samples included the untreated control and the three Vitamin C after-treatment samples. The original unexposed sample was retained as a reference for comparison. After exposure, the samples were visually compared with the original sample to observe changes in colour, as previously described in the Scope and Limitations of the Study.

RESULTS AND DISCUSSION

Effect of Vitamin C After-Treatment and Alum Mordant Concentration on Lightfastness

Table 5 presents the colour response of alum pre-mordanted silk and cotton dyed with *Terminalia catappa* leaves after 40 h of direct sunlight exposure. The dye concentration was kept at 50% w.o.f., while the alum mordant concentration was varied. The results showed a clear difference between silk and cotton. Greater colour changes were observed on silk, while the cotton samples remained relatively pale under the different treatment conditions.

Table 5: Visual lightfastness response of Vitamin C after-treated alum pre-mordanted silk and cotton dyed with *Terminalia catappa* leaves at different alum mordant concentrations after 40 h exposure to direct sunlight.



For silk, the exposed samples generally developed deeper golden-yellow to golden-brown shades compared with the original unexposed samples. The colour difference became more noticeable as the alum mordant concentration increased. The deepest shades were observed at the highest mordant concentration, particularly among the AT2 and AT3 samples. However, the degree of colour change was not the same for all Vitamin C treatment conditions.

Colour changes in natural dyes during exposure to air and light have been reported in previous studies. Plant colourants may undergo oxidation when exposed to atmospheric oxygen, while sunlight and ultraviolet radiation can also cause photo-oxidation or changes in natural colour compounds (Bukhari et al., 2023; Mazumder et al., 2026). Oxidative changes in the phenolic compounds of *Terminalia catappa* (Ketapang) have also been reported (Mazumder et al., 2026), and a similar darker colour after direct sunlight exposure was previously reported in Vitamin C after-treated silk (Faiz et al., 2016). The darker shades observed in the present study are therefore reported as post-exposure colour development.

The effect of alum concentration was more visible on silk. At 25% w.o.f. alum, the exposed samples showed colour changes from the original shade, but the differences among the treatment conditions were relatively small. The shades became deeper at 37.5% and 50% w.o.f. alum, with the strongest visual colour development observed at 50% w.o.f. The colour change on silk was more noticeable as the alum concentration increased.

A different result was observed on cotton. The cotton samples remained within a pale yellow range after sunlight exposure, with only small differences between the control and Vitamin C after-treated samples. Increasing the alum mordant concentration also did not produce the same degree of colour development observed on silk. Therefore, Vitamin C after-treatment produced a more limited visual effect on Ketapang-dyed cotton.

The different responses of silk and cotton are also consistent with their different dyeing behaviour. Silk is a protein fibre and generally has better affinity for many natural colourants, while cotton is a cellulosic fibre and may show lower uptake of some plant-based dyes (Sarma et al., 2025; Mazumder et al., 2026). In the present study, silk showed a clearer post-exposure colour response than cotton under the same dyeing, after-treatment and sunlight exposure conditions.

Overall, the effect of Vitamin C after-treatment differed according to fibre type and alum mordant concentration. The most noticeable post-exposure colour development was observed on silk at the highest alum concentration, while the treatment produced only small colour changes on cotton.

Suggestions for Further Study

Further studies may use standard laboratory lightfastness testing together with natural sunlight exposure. The present study used direct sunlight to compare the colour changes of the samples under the same exposure conditions. Future studies may use a controlled artificial light source, such as a Xenon arc lamp under ISO 105-B02, together with Blue Wool Standards to obtain standard lightfastness ratings from Grade 1 to Grade 8. The results from laboratory testing may then be compared with those obtained through direct sunlight exposure.

Instrumental colour measurement may also be included in future studies. A spectrophotometer can be used to record CIELAB colour coordinates before and after light exposure. The total colour difference can then be calculated to provide numerical data on the level of colour change. This may support the visual comparison of the dyed samples and provide additional information on small colour differences that may be less noticeable through visual observation.

Further studies may also focus on the chemical changes in the dyed silk samples before and after light exposure. FTIR or UV-Vis analysis may be used to record changes in polyphenolic compounds, tannins and other natural colour compounds. These methods may also provide further information on possible interactions between alum, Vitamin C and silk proteins. A separate study focusing on these chemical changes may provide more detailed information on the reactions within the dye, mordant, after-treatment and fibre system.

Different Vitamin C concentrations and alum mordant concentrations may also be used in future studies. The present study used a fixed Vitamin C concentration, while the alum concentration was varied. A wider range of concentrations may be compared to observe whether similar or different colour responses are produced. This may provide further information on the use of Vitamin C and alum in Ketapang dyeing under different treatment conditions.

The effect of treatment temperature and application method may also be studied separately. In the present study, Vitamin C was applied at different temperatures and using different treatment approaches. Future studies may compare these factors separately so that the effect of temperature can be observed without changing the application method. Other protein, cellulosic and synthetic fibres may also be included to compare their responses to the same dyeing and after-treatment conditions.

The dyeing recipe may also be applied in future textile art and design projects. Its use on decorative, wearable or other textile products may help to show how the dyeing and after-treatment methods perform in a practical setting. This would extend the study beyond laboratory samples and provide further information on the use of Ketapang dye and Vitamin C after-treatment in artistic textile applications.

CONCLUSION

This study observed the effect of different alum mordant concentrations and Vitamin C after-treatment on the lightfastness of *Terminalia catappa* (Ketapang) dyed cotton and silk fabrics. The dye concentration was kept constant, while three alum mordant concentrations and three Vitamin C after-treatment conditions were used. Treated and untreated samples were exposed to direct sunlight for 40 h and the colour changes were visually compared.

Different colour responses were observed between silk and cotton. The silk samples generally developed deeper shades after sunlight exposure, and the colour difference became more noticeable as the alum mordant concentration increased. The strongest post-exposure colour development was observed at the highest alum concentration, particularly among the Vitamin C after-treated samples.

Cotton showed a different response. The samples remained relatively pale under the different alum mordant and Vitamin C treatment conditions, with only small colour differences observed after sunlight exposure. Increasing the alum concentration did not produce the same level of post-exposure colour development observed on silk.

Overall, Vitamin C after-treatment produced a more noticeable effect on silk than on cotton under the conditions of this study. Alum mordant concentration was also associated with clearer colour differences on the silk samples. The findings provide further information on the use of Vitamin C after-treatment and different alum mordant concentrations in Ketapang dyeing and may support further studies on natural-dyed textile materials.

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Ethical Approval Statement

Ethical approval was not required for this study as it did not involve human participants, animals, or personal data. The research involved laboratory-based experimental work using textile materials, plant-based natural dye and lower-toxicity chemical auxiliaries.

Conflict of Interest

The author declare no conflict of interest.

Data Availability Statement

The data supporting the findings of this study are available from the author upon reasonable request. Additional experimental data not included in this paper are also available where relevant.

REFERENCES

1. Bukhari, M. N., Wani, M. A., Fatima, M., Bukhari, J. S. S., Shabbir, M., Rather, L. J., & Mohammad, F. (2023). Dyeing of Wool with Sappan Wood Natural Dye Using Metal Salts for Enhancement in Color and Fastness Properties. Journal of Natural Fibers, 20(2), 2208890. https://doi.org/10.1080/15440478.2023.2208890
2. Faiz, F. A., Ngo, J. S. K., & Bujang, K. B. (2016). Ascorbic acid treatment to improve the light fastness or as reducing agent on silk fabric dyed with pulverised natural dyes. Research Journal of Textile and Apparel, 20(2), 74–86. https://doi.org/10.1108/RJTA-11-2014-0036
3. Krisnawati, M., Cahyani, I. W. N., Paramita, O., & Kusumastuti, A. (2022a). Textile natural dye powder of Terminalia catappa leaves. IOP Conference Series: Earth and Environmental Science, 969(1), 012038. https://doi.org/10.1088/1755-1315/969/1/012038
4. Krisnawati, M., Cahyani, I. W. N., Paramita, O., & Kusumastuti, A. (2022b). Textile natural dye powder of Terminalia catappa leaves. IOP Conference Series: Earth and Environmental Science, 969(1), 012038. https://doi.org/10.1088/1755-1315/969/1/012038
5. Kumarmath, P., Kawatal, A., & Nimbargi, K. (2022). A Review On Extraction Of Dye From Terminalia Catappa Hull: A Substitute To Synthetic Dyes (SSRN Scholarly Paper No. 4047977). Social Science Research Network. https://papers.ssrn.com/abstract=4047977
6. Lin, C.-C., Chen, Y.-L., Lin, J. M., & Ujiie, T. (1997). Evaluation of the Antioxidant and Hepatoprotective Activity of Terminalia catappa. The American Journal of Chinese Medicine, 25(02), 153–161. https://doi.org/10.1142/S0192415X97000172
7. Linh, H. T., Chat, T. V., & Tan, V. D. (2017). EVALUATION OF THE ECOLOGICAL PROPERTIES OF COTTON FABRIC AND SILK FABRIC DYED WITH COLORANTS EXTRACTED FROM THE TERMINALIA T. CATAPPA LEAVES. Journal of Applied Science and Technology, 13, 74–77.

8. Mazumder, B. C., Fariz, A. A., Hossain, M. M., Momin, S. A., Uddin, Md. K., Mahmud, Md. H., Alam, M. M., & Esposito Corcione, C. (2026). Sustainable Mordant-Free Dyeing of Nylon with Terminalia catappa Leaf Extract: Process Optimization, Dye–Fiber Interaction, and Fastness Performance. Processes, 14(13), 2148. https://doi.org/10.3390/pr14132148
9. Murwanti, A., Hazmi, F. A., & Kamal, F. P. (2025). Sustainable batik dyeing with ketapang (terminalia catappa) leaves: A practice-led experimental study on color retention and design innovation. International Journal of Visual and Performing Arts, 7(1), 207–217. https://doi.org/10.31763/viperarts.v7i1.1698
10. Mwangi, W. C., Waudo, W., Shigwenya, M. E., & Gichuki, J. (2024). Phytochemical characterization, antimicrobial and antioxidant activities of Terminalia catappa methanol and aqueous extracts. BMC Complementary Medicine and Therapies, 24(1), 137. https://doi.org/10.1186/s12906-024-04449-7
11. Sarma, P., Bano Choudhury, F., Basumatari, D., Kalita, K., Sekhar Ghosh, S., Basnet Baruah, B., Rahman, S., Das, J., Mech, B., Das, S., Baruah, P., Baruah, H., Khargharia, S., & Kalita, T. (2025a). Development and Evaluation of Indigenous Natural Dyes: Extraction Methods, Absorption Efficiency, and Color Fastness on Eri Silk. Journal of Natural Fibers, 22(1), 2465670. https://doi.org/10.1080/15440478.2025.2465670
12. Sarma, P., Bano Choudhury, F., Basumatari, D., Kalita, K., Sekhar Ghosh, S., Basnet Baruah, B., Rahman, S., Das, J., Mech, B., Das, S., Baruah, P., Baruah, H., Khargharia, S., & Kalita, T. (2025b). Development and Evaluation of Indigenous Natural Dyes: Extraction Methods, Absorption Efficiency, and Color Fastness on Eri Silk. Journal of Natural Fibers, 22(1), 2465670. https://doi.org/10.1080/15440478.2025.2465670
13. Vadwala, Y., & Kola, N. (2017). NATURAL DYES EXTRACTED FROM WASTE LEAVES OF TERMINALIA CATAPPA LOCALLY KNOWN AS TROPICAL ALMOND AND ITS APPLICATION ON SILK FABRICS PRETREATED WITH ECO FRIENDLY AND NONECO-FRIENDLY MORDANTS. International Journal of Research -GRANTHAALAYAH, 5(5), 125–137. https://doi.org/10.29121/granthaalayah.v5.i5.2017.1845