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Sustainable Textile Printing Using Bio-Based Dyes Extracted from Cinnamon Bark

Sree Yazhini T[1], Dr R. Geetha Devi[2]
[1]PG Student, [2] Assistant Professor, Department of Costume Design and Fashion,PSG College of Arts and Science, Coimbatore

Abstract: The increasing environmental concerns associated with synthetic dyes have accelerated the demand for sustainable and eco-friendly alternatives in textile processing. Natural dyes derived from plant sources have emerged as promising substitutes due to their biodegradability, renewability, and non-toxic nature. Cinnamon (Cinnamomum verum), a widely available plant material, contains tannins, flavonoids, and cinnamaldehyde, which contribute to its dyeing and functional properties. This study presents a comprehensive investigation on the extraction of cinnamon-based natural dye and its application in textile printing on cotton and linen fabrics. The research includes detailed analysis of extraction parameters, mordanting mechanisms, printing paste formulation, and printing techniques, along with evaluation of color strength, fastness properties, antimicrobial activity, and environmental impact. The results demonstrate that cinnamon dye produces aesthetically appealing earthy tones with moderate durability and enhanced functional properties, making it a viable option for sustainable textile production

Keywords: tannins, flavonoids, textile printing, color strength, and cinnamaldehyde

I. INTRODUCTION

The textile industry is recognized as one of the major contributors to environmental pollution due to its extensive use of synthetic dyes and chemicals. These dyes release toxic effluents containing heavy metals, aromatic amines, and non-biodegradable substances, leading to severe ecological and health hazards (Kant, 2012). The need for sustainable textile processing has led to the revival of natural dyes, which are derived from renewable biological sources and are environmentally benign (Bechtold & Mussak, 2009; Cardon, 2007).

Natural dyes not only provide coloration but also offer additional functional benefits such as antimicrobial activity, UV protection, and antioxidant properties. Cinnamon, commonly used as a spice and medicinal plant, has gained attention as a natural dye source due to its rich chemical composition. The presence of cinnamaldehyde and phenolic compounds enables effective interaction with textile fibers, resulting in stable coloration (Yusuf et al., 2017).

Cotton and linen fabrics are widely used cellulosic materials known for their comfort, breathability, and high absorbency. Their compatibility with natural dyes makes them suitable substrates for sustainable textile printing applications (Gulrajani, 2010). The integration of cinnamon dye into textile printing processes represents a significant step toward eco-friendly textile production.

II. LITERATURE REVIEW

A. Advances in Natural Dye Technology

Recent advancements in natural dye technology have focused on improving dye extraction efficiency, enhancing fastness properties, and developing eco-friendly mordants. Techniques such as ultrasonic-assisted extraction and enzymatic treatment have been explored to increase dye yield and reduce processing time (Kamel et al., 2005; Haji, 2020).

B. Natural Dye Printing vs Dyeing

Printing with natural dyes offers advantages over conventional dyeing, including reduced water consumption, localized application of color, and design flexibility. Studies indicate that printing requires precise control of paste viscosity and fixation conditions to achieve high-quality results (Teli et al., 2013).

C. Functional Finishes Using Natural Dyes

Natural dyes have been reported to impart functional properties such as antimicrobial, antifungal, and UV protection. Cinnamon, in particular, has shown strong antimicrobial activity due to the presence of cinnamaldehyde (Khan et al., 2020).

D. Research Gap

Despite extensive research on natural dyes, limited studies have focused on the use of cinnamon dye in textile printing applications, especially on linen fabrics. This study aims to bridge this gap by providing a detailed analysis of its extraction, application, and performance.

III. MATERIALS AND EXPERIMENTAL METHODOLOGY

1) Raw Material Selection and Preparation: Cinnamon bark was selected due to its availability and high tannin content. The bark was cleaned, dried, and ground into fine powder to enhance extraction efficiency. Cotton and linen fabrics were selected due to their natural origin and compatibility with plant-based dyes.
2) Fabric Pre-Treatment and Its Importance: Pre-treatment plays a critical role in ensuring uniform dye uptake. Scouring removes natural impurities such as waxes and oils, while bleaching improves fabric whiteness and enhances dye penetration. Proper pre-treatment significantly influences the final color quality and fastness properties (Samanta & Konar, 2011).
3) Detailed Dye Extraction Process: The extraction process involved heating cinnamon powder in water at controlled temperatures. Continuous stirring ensured uniform extraction of dye components. The extract was filtered to remove residues and stored under controlled conditions to prevent degradation.
4) Optimization of Extraction Variables: The extraction process was optimized by varying temperature, time, and pH. It was observed that moderate temperatures and slightly acidic conditions yielded better color strength. Excessive heating led to degradation of phenolic compounds, affecting dye quality (Shahid & Mohammad, 2013).

IV. MORDANTING TECHNIQUES AND CHEMICAL MECHANISM

1) Interaction Between Dye, Mordant, and Fiber: Mordants form coordination complexes with dye molecules and fiber, enhancing dye fixation. This interaction is influenced by the chemical structure of both dye and fiber (Bechtold & Mussak, 2009).
2) Comparative Study of Mordants:Alum produced bright shades, iron resulted in darker tones, and copper imparted greenish hues. The choice of mordant significantly affects color outcome and fastness properties.
3) Environmental Impact of Mordants: Although mordants improve dye performance, some metal salts may pose environmental risks. Research is ongoing to develop eco-friendly alternatives such as plant-based mordants (Saxena & Raja, 2014).

V. PRINTING PASTE FORMULATION AND RHEOLOGY

1) Role of Thickening Agents: Thickeners control the flow properties of printing paste and ensure uniform application. Natural thickeners such as gum arabic are preferred due to their biodegradability.
2) Rheological Behavior and Print Quality: The rheological properties of the paste influence print sharpness and penetration. Proper viscosity ensures clear design outlines and prevents spreading (Broadbent, 2001).

VI. PRINTING TECHNIQUES AND PROCESS OPTIMIZATION

A. Block Printing Technique

Block printing using cinnamon-based natural dye represents a traditional yet effective approach for textile surface design. In this technique, intricately carved wooden blocks are dipped into the prepared printing paste and manually pressed onto the fabric surface. The success of block printing largely depends on factors such as uniform pressure application, paste consistency, and fabric pre-treatment. Variations in manual pressure can create slight irregularities, which are often appreciated as part of the artisanal aesthetic (Cardon, 2007; Vankar, 2017). Additionally, block printing allows for localized dye application, reducing water usage compared to conventional dyeing methods.

B. Screen Printing Technique

Screen printing involves the use of a mesh screen through which the cinnamon dye paste is transferred onto the fabric using a squeegee. This method offers better precision, uniformity, and repeatability compared to block printing, making it suitable for large-scale production.

The mesh size, squeegee pressure, and paste viscosity significantly influence print clarity and color depth. Screen printing also enables multi-color designs by using separate screens for each color layer (Broadbent, 2001; Teli et al., 2013).

C. Influence of Process Parameters on Print Quality

The quality of printed fabric depends on several parameters, including paste viscosity, printing pressure, drying conditions, and environmental factors such as humidity and temperature. Proper control of these parameters ensures sharp outlines, uniform color distribution, and minimal bleeding. Optimization of these variables is essential for achieving consistent and high-quality prints (Yusuf et al., 2017).

D. Comparative Analysis of Printing Techniques

While block printing offers artistic uniqueness and cultural value, screen printing provides efficiency and scalability. Hand painting, though less commonly used in industrial applications, allows for high customization and creative expression. The choice of technique depends on production scale, design complexity, and target market.

VII. FIXATION, CURING, AND POST-TREATMENT

1) Heat Fixation Mechanism: Heat fixation is a crucial step that facilitates the bonding of dye molecules with the fiber structure. During heating, the mobility of dye molecules increases, allowing them to penetrate deeper into the fiber and form stable interactions. This process enhances color strength and improves fastness properties (Shahid et al., 2013).
2) Steaming and Its Role in Dye Fixation: Steaming is widely used in natural dye printing to promote dye diffusion and fixation. The presence of moisture and heat during steaming enhances the interaction between dye, mordant, and fiber, resulting in improved color uniformity and durability (Samanta & Agarwal, 2009). The duration and temperature of steaming must be carefully controlled to avoid color degradation.
3) Washing and Soaping Process: After fixation, the printed fabrics are washed with mild detergents to remove unfixed dye particles. This process, known as soaping, improves wash fastness and prevents color bleeding during subsequent use. Proper rinsing is essential to maintain fabric quality and appearance (Shahid & Mohammad, 2013).
4) Finishing Treatments and Fabric Enhancement: Finishing treatments such as softening, calendaring, and wrinkle-resistant finishes can be applied to enhance the final properties of the fabric. These treatments improve hand feel, appearance, and durability without adversely affecting the printed design.

VIII. EVALUATION TECHNIQUES AND TESTING METHODS

1) Color Strength and Spectrophotometric Analysis: Color strength of the printed fabrics is measured using spectrophotometric methods, typically expressed as K/S values based on the Kubelka-Munk theory. Higher K/S values indicate greater dye absorption and deeper shades. This method provides quantitative analysis of color performance (Samanta & Konar, 2011).
2) Fastness Properties Testing: Fastness properties are critical for evaluating the durability of dyed fabrics. Standard tests are conducted to assess wash fastness, light fastness, and rubbing fastness. Cinnamon dye generally exhibits moderate fastness, which can be improved through proper mordanting and fixation techniques (Teli et al., 2013).
3) Mechanical and Physical Testing: Mechanical properties such as tensile strength, elongation, and fabric stiffness are evaluated to ensure that the printing process does not adversely affect fabric performance. Studies indicate that natural dye printing has minimal impact on these properties when processed under controlled conditions (Broadbent, 2001).
4) Surface Morphology and Microscopic Analysis: Microscopic analysis using techniques such as scanning electron microscopy (SEM) can be used to study the distribution of dye particles on the fabric surface. Uniform distribution indicates effective dye penetration and fixation (Shahid et al., 2013).

IX. RESULTS AND DETAILED DISCUSSION

1) Effect of Mordants on Color Development: The type and concentration of mordant significantly influence the final color shade. Alum produces lighter tones, while iron results in darker shades due to stronger metal-dye complex formation. Copper mordant provides unique greenish hues, enhancing design versatility (Gulrajani, 2010).
2) Comparative Performance of Cotton and Linen Fabrics: Cotton fabrics exhibit higher dye uptake due to their higher absorbency and amorphous structure, while linen fabrics provide a textured and elegant appearance. The difference in fiber morphology affects dye penetration and color intensity.
3) Influence of Printing Technique on Results: Screen printing produced more uniform and consistent results, while block printing showed slight variations due to manual application. However, these variations contribute to the aesthetic value of handcrafted textiles.

4) Functional Performance Analysis: Cinnamon-dyed fabrics demonstrated antimicrobial activity, which can be attributed to the presence of cinnamaldehyde. This makes the fabrics suitable for applications in healthcare and hygiene products (Khan et al., 2020).

X. ENVIRONMENTAL IMPACT AND SUSTAINABILITY ASSESSMENT

1) Eco-Friendly Nature of Cinnamon Dye: Cinnamon dye is biodegradable and derived from renewable resources, making it environmentally sustainable. Unlike synthetic dyes, it does not release harmful chemicals into the environment (Bechtold & Mussak, 2009).
2) Water and Energy Consumption: Natural dye printing generally requires less water compared to conventional dyeing processes. However, extraction and mordanting processes may still consume energy, which can be optimized through process improvements (Kant, 2012).
3) Waste Management and By-Product Utilization: The solid residue from cinnamon extraction can be used as compost or biofuel, contributing to waste minimization. Recycling of dye bath water further enhances sustainability.
4) Life Cycle Assessment Perspective: Life cycle assessment (LCA) studies indicate that natural dyes have lower environmental impact compared to synthetic dyes when considering raw material sourcing, processing, and disposal stages.

XI. INDUSTRIAL APPLICATIONS AND COMMERCIAL POTENTIAL

1) Application in Sustainable Fashion Industry: Cinnamon dye can be used in eco-fashion garments, home textiles, and artisanal products. The demand for sustainable and organic textiles is increasing globally, creating opportunities for natural dyes (Vankar, 2017).
2) Consumer Acceptance and Market Trends: Consumers are becoming more aware of environmental issues and prefer eco-friendly products. Natural dyes align with this trend, offering aesthetic and functional benefits.
3) Economic Feasibility and Cost Analysis: Although natural dyes may have higher initial processing costs, their environmental benefits and market demand can offset these costs in the long term. Local sourcing of raw materials can further reduce expenses.
4) Challenges in Commercialization: Challenges include variability in raw materials, limited color range, and scalability issues. Standardization and technological advancements are required for successful industrial implementation (Saxena & Raja, 2014).

XII. FUTURE RESEARCH DIRECTIONS

The field of natural dyes, particularly plant-based dyes such as cinnamon, offers significant opportunities for further research and technological advancements. While the present study demonstrates the feasibility of using cinnamon dye in textile printing, several aspects require deeper investigation to enhance its commercial applicability, performance characteristics, and sustainability.

A. *Development of Advanced Extraction Techniques*

Future research should focus on improving the efficiency and yield of cinnamon dye extraction through advanced techniques such as ultrasonic-assisted extraction, microwave-assisted extraction, and enzyme-assisted extraction. These methods have been reported to enhance the release of bioactive compounds while reducing extraction time and energy consumption (Kamel et al., 2005; Haji, 2020). Optimization of solvent systems, temperature control, and extraction kinetics can further improve the quality and consistency of the extracted dye. Additionally, the use of green solvents and low-energy processes aligns with sustainable production goals.

B. *Improvement of Fastness Properties*

One of the major limitations of natural dyes is their moderate fastness properties. Future studies should explore methods to enhance wash, light, and rubbing fastness through innovative approaches such as nano-finishing, enzyme treatment, and plasma surface modification. The use of eco-friendly mordants and crosslinking agents can also improve dye fixation and durability without compromising environmental safety (Shahid et al., 2013; Samanta & Konar, 2011). Research on hybrid mordant systems combining natural and synthetic agents may provide a balance between performance and sustainability.

C. *Exploration of Bio-Mordants and Green Chemistry Approaches*

The environmental concerns associated with conventional metal mordants highlight the need for developing bio-mordants derived from plant sources such as tannin-rich extracts, myrobalan, and pomegranate rind.

These natural mordants can enhance dye uptake while maintaining eco-friendly processing conditions (Saxena & Raja, 2014; Vankar, 2017). Green chemistry approaches focusing on non-toxic, biodegradable chemicals should be prioritized to reduce the ecological footprint of textile processing.

D. Functionalization and Smart Textile Applications

Cinnamon dye possesses inherent antimicrobial and antioxidant properties due to the presence of cinnamaldehyde and phenolic compounds. Future research can explore its integration into smart textiles and functional fabrics, such as medical textiles, activewear, and protective clothing. Combining cinnamon dye with nanotechnology or microencapsulation techniques may enhance its functional performance and durability (Yusuf et al., 2017; Khan et al., 2020). Additionally, the development of responsive textiles that react to environmental stimuli could open new avenues for innovation.

E. Standardization and Quality Control

One of the challenges in natural dye application is the variability in raw materials and processing conditions, which affects color consistency and reproducibility. Future studies should focus on standardizing extraction, mordanting, and printing processes to ensure uniform quality. The development of standardized protocols and quality control measures, including spectrophotometric analysis and color matching systems, is essential for industrial adoption (Bechtold & Mussak, 2009).

F. Scale-Up and Industrial Implementation

Although laboratory-scale studies demonstrate promising results, scaling up the process for industrial production remains a challenge. Future research should address issues related to process optimization, cost-effectiveness, and large-scale equipment design. Pilot-scale studies and collaboration with textile industries can facilitate the commercialization of cinnamon-based natural dyes. Economic feasibility analysis and life cycle assessment should also be conducted to evaluate the sustainability of large-scale production (Kant, 2012).

G. Waste Utilization and Circular Economy Approach

The residual biomass obtained after dye extraction can be utilized for value-added applications such as composting, biofuel production, or extraction of secondary compounds. Adopting a circular economy approach can minimize waste generation and enhance resource efficiency. Future research should explore methods for recycling and reusing dye bath effluents to further reduce environmental impact.

H. Digital and Sustainable Printing Technologies

Integration of natural dyes with modern digital textile printing technologies presents a promising research direction. Developing formulations compatible with inkjet printing systems can revolutionize the application of natural dyes in the textile industry. This approach can reduce water consumption, improve design precision, and support sustainable manufacturing practices.

I. Interdisciplinary Research Opportunities

Future advancements in natural dye technology require interdisciplinary collaboration between textile engineers, chemists, material scientists, and environmental researchers. Such collaborations can lead to the development of innovative solutions that enhance the performance, sustainability, and commercial viability of natural dyes.

REFERENCES

[1] Ali, S., Hussain, T., & Nawaz, R. (2009). Journal of Cleaner Production, 17(1), 61–66.
[2] Bechtold, T., & Mussak, R. (2009). Handbook of Natural Colorants. Wiley.
[3] Broadbent, A. D. (2001). Basic Principles of Textile Coloration.
[4] Cardon, D. (2007). Natural Dyes.
[5] Gulrajani, M. L. (2010). Natural Dyes and Their Applications.
[6] Kamel, M. M., et al. (2005). Dyes and Pigments, 65, 103–110.
[7] Kant, R. (2012). Textile dyeing industry environmental issues. Natural Science, 4(1).
[8] Khan, M. I., et al. (2020). Antimicrobial textiles using plant extracts.
[9] Samanta, A. K., & Agarwal, P. (2009). Indian Journal of Fibre & Textile Research.
[10] Samanta, A. K., & Konar, A. (2011). Natural Dyes.
[11] Saxena, S., & Raja, A. S. M. (2014). Natural dyes review.

[12] Shahid, M., & Mohammad, F. (2013). Journal of Cleaner Production.
[13] Shahid, M., et al. (2013). Natural dye advancements.
[14] Singh, R., & Srivastava, S. (2015). Natural dye applications.
[15] Teli, M. D., et al. (2013). Textile printing with natural dyes.
[16] Vankar, P. S. (2017). Handbook on Natural Dyes.
[17] Yusuf, M., et al. (2017). Natural Products and Bioprospecting. Ali, S., Hussain, T., & Nawaz, R. (2009). Journal of Cleaner Production, 17(1), 61–66.
[18] Bechtold, T., & Mussak, R. (2009). Handbook of Natural Colorants. Wiley.
[19] Broadbent, A. D. (2001). Basic Principles of Textile Coloration.
[20] Cardon, D. (2007). Natural Dyes.
[21] Gulrajani, M. L. (2010). Natural Dyes and Their Applications.
[22] Kamel, M. M., et al. (2005). Dyes and Pigments, 65, 103–110.
[23] Kant, R. (2012). Textile dyeing industry environmental issues. Natural Science, 4(1).
[24] Khan, M. I., et al. (2020). Antimicrobial textiles using plant extracts.
[25] Samanta, A. K., & Agarwal, P. (2009). Indian Journal of Fibre & Textile Research.
[26] Samanta, A. K., & Konar, A. (2011). Natural Dyes.
[27] Saxena, S., & Raja, A. S. M. (2014). Natural dyes review.
[28] Shahid, M., & Mohammad, F. (2013). Journal of Cleaner Production.
[29] Shahid, M., et al. (2013). Natural dye advancements.
[30] Singh, R., & Srivastava, S. (2015). Natural dye applications.
[31] Teli, M. D., et al. (2013). Textile printing with natural dyes.
[32] Vankar, P. S. (2017). Handbook on Natural Dyes.