IMPROVING THE DYEING AFFINITY OF NATURAL DYES FOR COTTON FABRICS USING NANOTECHNOLOGY: A COMPARATIVE EVALUATION OF NANOPARTICLES

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DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning, and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works.

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The above candidate has carried out research for the PhD thesis/dissertation under my supervision. I confirm that the declaration made above by the student is true and correct.

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Signature of the Supervisor: Date: 2026/03/12

Name of Supervisor: Senior Professor C.A. Nandana Fernando

Signature of the Supervisor: Date: 2026/03/15

DEDICATION

I dedicate this work with thoughtful gratitude and deep respect to my beloved parents, whose unwavering love, encouragement and numerous sacrifices have provided the foundation for every achievement in my academic journey. Their faith in my abilities has continually inspired me to overcome challenges and pursue excellence. I also sincerely dedicate this thesis to my respected teachers, academic mentors and advisors, whose invaluable guidance, patience and massive knowledge have greatly improved my understanding and nurtured my passion for sustainable textile science and research. Their mentorship has been instrumental in shaping my academic career and personal growth. Moreover, I extend my dedication to my family members and friends, whose continuous support and motivation have been an invaluable source of strength throughout my research. Finally, I dedicate this work to all researchers, innovators and advocates who tirelessly strive toward developing environmentally friendly and sustainable solutions within the textile industry. May this research serve as a meaningful contribution to our collective goal of creating a greener, healthier, and more sustainable future for generations to come.

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ABSTRACT

The growing demand for eco-friendly textile dyeing has renewed interest in natural dyes due to their biodegradability, non-toxicity, and sustainable source. However, their low affinity for cotton fibres and poor colourfastness properties remain major limitations. These challenges are typically addressed using metallic mordants, which increase significant environmental and health concerns. Therefore, the present study aims to enhance the dyeing affinity and fastness properties of natural dyes on cotton fabrics through a nanotechnology-based approach. The objectives of this study are to synthesise and isolate nanoparticles, extraction of natural dyes from selected plant sources, apply nanoparticles as pre-treatments to cotton fabrics, and evaluate their effect on dye performance. Cellulose nanocrystals (CNCs), chitosan nanocrystals (ChsNCs), and iron nanoparticles (FeNPs) were either synthesized or isolated and subsequently characterized using analytical techniques. Natural dye extracts were obtained from the four selected plant leaves of *Mangifera indica*, *Tectona grandis*, *Lannea coromandelica* and *Bridelia retusa* using aqueous extraction methods, and characterized using analytical techniques. The nanoparticles were used as pre-treatment agents for cotton fabrics prior to dyeing with the natural extracts. The dyed fabrics were assessed for colour properties to evaluate dye uptake and performance. Furthermore, the morphology and interactions among dye molecules, nanoparticles, and cotton fibres were analyzed using scanning electron microscopy (SEM) and Fourier transform infrared (FTIR) spectroscopy. The nanoparticle-treated fabrics showed significantly improved dye performance compared to the untreated sample. Among the nanoparticle treatments, CNCs and ChsNCs exhibited more effective interactions with dye molecules and cotton fibres compared to FeNPs. This study confirms that functionalized nanoparticles offer an efficient, environmentally benign approach to improving the performance of natural dyes on cotton fabrics, thereby enhancing sustainable textile processing and reducing reliance on hazardous mordants and synthetic dyes.

Keywords: *Cotton fabric, Dye affinity, Eco-friendly, Nanoparticle, Natural dye*

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LIST OF ABBREVIATIONS

Abbreviation	Description
3D	Three-Dimensional
Ag	Silver
AgNPs	Silver Nanoparticles
AR grade	Analytical Reagent Grade
ATR	Attenuated Total Reflectance
Au	Gold
AuNPs	Gold Nanoparticles
BOD	Biological Oxygen Demand
C=O	Carbonyl Group
CFU/ml	Colony-Forming Units per milliliter
C–H	Carbon–Hydrogen Bond
ChsNCs	Carboxylated Chitosan Nanocrystals
CIE Lab	Colour Coordinates
CNCs	Cellulose Nanocrystals
CNPs	Cellulose Nanofibres
COD	Chemical Oxygen Demand
C–O–O–C	Ether Linkage
COOH	Carboxyl Group
CuNPs	Copper Nanoparticles
CuO	Copper Oxide
E. coli	*Escherichia coli*
E. faecalis	*Enterococcus faecalis*
EDX	Energy Dispersive X-Ray
Fe	Iron
$FeCl_3$	Ferric Chloride
FeNPs	Iron Nanoparticles
FTIR	Fourier-Transform Infrared
g	gram
GC-MS	Gas Chromatography-Mass Spectrometry

K. pneumoniae	*Klebsiella pneumoniae*
K/S	Colour Strength
L	Liter
LbL	Layer-by-Layer
LCA	Life Cycle Assessment
ml	milliliter
MLR	Material-to-Liquor Ratio
NH_2	Amine Group
Nm	Nanometers
N–O	Nitroso Group
NPs	Nanoparticles
o.w.f.	On the Weight of Fabric
OH	Hydroxyl Group
R	Reflectance
RUI	Relative Unlevelness Index
S. aureus	*Staphylococcus aureus*
S=O	Sulfoxide Group
SEM	Scanning Electron Microscopy
SiO_2	Silicon Dioxide
TEM	Transmission Electron Microscope
TiO_2	Titanium Dioxide
UPF	Ultraviolet Protection Factor
UV	Ultraviolet
UV-Vis	Ultraviolet–Visible Spectroscopy
w/v	Weight/Volume
w/w	Weight/Weight
XRD	X-ray Diffraction
ZnO	Zinc Oxide
µl	Microliter