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ECO-FRIENDLY FABRICATION OF SPHEROID CELLULOSE-SILVER NANOCOMPOSITES MEDIATED BY *Ipomoea tridentata* AND THEIR PHOTOCATALYTIC AND ANTIBACTERIAL ACTIVITIES

H. Usha[1], D. Santhi Priya[2], J. Chandrasekhar Rao[3], P. Jayarangarao[4], M. Sankara Rao[5], Preetha Bhadra[6] , and A. Satheesh[7,✉]

[1]Department of Chemistry, Govt. Polytechnic for Women, Srikakulam, Andhra Pradesh, India
[2]Department of Chemistry, Government Degree College, Gajapathinagaram (Andhra Pradesh), India
[3]Department of Physics, Government Degree College, Rajam, Vizianagaram (Andhra Pradesh), India
[4]Department of Chemistry, BABA Institute of Technology and Sciences, Visakhapatnam (Andhra Pradesh), India
[5]Department of Chemistry, Government Degree College, Puttur, Tirupati, Andhra Pradesh, India
[6]Department of Biotechnology, MS Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha, India
[7]Department of Chemistry, Centurion University of Technology and Management, Vizianagaram, Andhra Pradesh, India
✉Corresponding author: satheesh@cutmap.ac.in

ABSTRACT

In the present study, cellulose/silver nanocomposites (Cell/ITLL Ag NCs) were successfully synthesized via a green and sustainable approach using *Ipomoea tridentata* leaf extract as both reducing and stabilizing agent. The formation and structural properties of the nanocomposites were confirmed through FTIR, XRD, SEM, TEM, and UV–Vis analyses, which revealed the presence of well-dispersed silver nanoparticles. Among the synthesized samples, the nanocomposite prepared with 50 mM $AgNO_3$ exhibited uniformly distributed nanoparticles with an average size of 32.65 nm. The prepared nanocomposites demonstrated significant antimicrobial activity against both Gram-negative (*Escherichia coli*, *Pseudomonas aeruginosa*) and Gram-positive (*Staphylococcus aureus*, *Bacillus subtilis*) bacteria, with inhibition zones increasing proportionally with $AgNO_3$ concentration. Furthermore, the nanocomposites showed excellent photocatalytic performance in the degradation of methyl red dye, achieving up to 85% degradation efficiency using 100 mg of catalyst. These findings highlight the potential of the synthesized nanocomposites as effective multifunctional materials for environmental remediation and biomedical applications.

Keywords: *Ipomoea tridentata* (L.), Cellulose/Silver, Methyl Red, Photocatalytic Degradation,*Pseudomonas Aeruginosa.*

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INTRODUCTION

In recent years, silver nanoparticles (AgNPs) have been widely explored using electrochemical, chemical reduction, and biological synthesis strategies.[1–6] Among these, green approaches employing plant extracts have gained particular attention, since they not only accelerate nanoparticle formation but also act as natural stabilizing and reducing agents.[7,8] Plant-derived metabolites such as terpenoids, flavonoids, amino acids, proteins, alkaloids, and enzymes contribute significantly by functioning as capping agents during nanoparticle stabilization.[9,10] Several studies have reported the successful incorporation of silver nanoparticles into polymeric matrices using plant extracts, leading to the development of cellulose–silver nanocomposites with excellent biocompatibility and potential applications in antibacterial coatings, textiles, and biomedical devices.[11-13] *Ipomoea tridentata* (L.), a medicinally valuable plant, is known for

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its diverse therapeutic activities, including diuretic, antiallergic, astringent, laxative, antipyretic, spasmolytic, and tonic properties.[14,15]Phytochemical analysis of the leaves has identified several bioactive compounds—including 3,5-caffeoylquinic acid, quercetin-3-O-rhamnoside, kaempferol-3-O-rhamnoside, luteolin-7-O-glucoside, β-sitosterol, and stigmasterol-that can effectively function as both reducing and capping agents in nanoparticle synthesis.[16-18] These bioactive molecules, collectively termed ITLLs, are capable of reducing Ag^{+}ions into metallic silver when incorporated within a cellulose framework.Previous investigations have also highlighted the antioxidant and radical scavenging capabilities of AgNPs and cellulose–Ag nanocomposites, demonstrating their activity in both in vitro and in vivo models.[19-21] Moreover, silver-based nanostructures have been linked to anticancer potential through modulation of cellular morphology, metabolic pathways, and viability.[22-27] With the rapid expansion of industrialisation worldwide, issues such as water contamination and soil pollution have intensified, threatening ecosystems and human health.[28,29] In this study, silver nanoparticles (AgNPs) were synthesized in situ within a cellulose matrix using leaf extract of *Ipomoea tridentata*, leading to the formation of cellulose–silver nanocomposites (Cell/ITLL Ag NCs). The resulting nanocomposites were thoroughly characterized using FTIR, X-ray diffraction (XRD), UV–Visible spectroscopy, scanning electron microscopy (SEM), and transmission electron microscopy (TEM) to investigate their structural, chemical, and morphological properties.Furthermore, their antimicrobial efficacy and photocatalytic performance were systematically investigated to assess their potential for biomedical and environmental applications. This research contributes to SDG-12: Responsible Consumption and Production by promoting an eco-friendly synthesis route that utilizes Ipomoea tridentata as a natural reducing and stabilising agent. By minimizing the use of hazardous chemicals and adopting sustainable fabrication methods, it supports cleaner production practices. Additionally, the development of functional cellulose–silver nanocomposites with photocatalytic and antibacterial properties enhances resource efficiency and encourages the design of environmentally responsible materials, thereby aligning with global efforts toward sustainable consumption and production.

EXPERIMENTAL

Plant Material

Fresh leaves of *Ipomoea tridentata* (L.) were gathered from Baddipeta village, Kotabommali Mandal, Srikakulam District, Andhra Pradesh, India (Fig.-1). The plant samples were carefully washed with distilled water to eliminate dust and other surface contaminants, and then allowed to air-dry at room temperature under laboratory conditions for six days. Once fully dried, the leaves were cut into small pieces for further processing. For the preparation of the extract, 20 g of the dried leaf material (Fig.-2) was added to 300 mL of de-ionised water and heated at 82 °C for 25 minutes. After heating, the mixture was filtered using Whatman No. 1 filter paper to obtain a clear filtrate, which was then collected and preserved for subsequent experimental use.

Fig.-1 and 2: *Ipomoea tridentata* (L.) leaves and Dried *Ipomoea tridentata* (L.) Leaf Powder used for Aqueous Extract Preparation

Dissolution of Cellulose

A solvent system consisting of 8 wt% sodium hydroxide (NaOH) and 15 wt% urea ($CO(NH)_2$) was first prepared and cooled to -13^0C. Into this pre-chilled solution, 5 wt% cotton linter pulp was gradually introduced under vigorous stirring at room temperature. After mixing for 3 minutes, the suspension was

centrifuged at 7150 rpm and 6^0C for 15 minutes to separate undissolved residues. The resulting transparent cellulose solution was collected and stored at 6 °C for subsequent experiments.[12]

Preparation of Cellulose/ITLL Composite Films

The dried Ipomoea tridentata leaf extract was first dehydrated in a hot air oven to ensure complete removal of moisture. The dried powder was then incorporated into the cellulose solution and thoroughly homogenised using a mechanical stirrer. To remove entrapped air bubbles, the mixture was subjected to a degassing process. Film casting was carried out by pouring the cellulose/ITLL mixture onto pre-cleaned glass plates. The coated plates were immersed in water, and the pH of the medium was adjusted with dilute sulfuric acid to facilitate film regeneration. The regenerated composite films were carefully washed several times with distilled water and subsequently stored in a water bath until further use.

Preparation of Cellulose/ITLL Ag NC Composite Films

Separate aqueous solutions of silver nitrate ($AgNO_3$) were prepared at concentrations of 20, 40, and 60 mM. The preformed wet cellulose/ITLL films were then immersed individually in these solutions and kept under constant stirring for 25 hours. Throughout the reaction period, a noticeable colour transition of the films from pale yellow to dark brown was observed, indicating the successful in situ formation of silver nanoparticles within the cellulose matrix. Following synthesis, the films were carefully washed with distilled water to remove any unreacted ions or surface residues. They were then dried at room temperature and stored in desiccators until further use.

Characterization of Samples

Fig.-3: SEM images of Cell/ ITLL

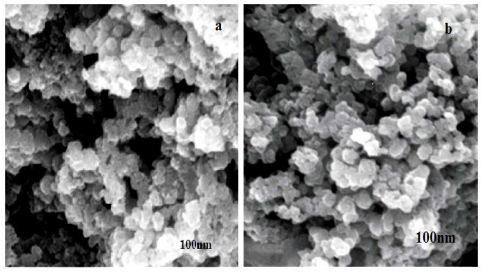

Fig.-4: SEM images of (a) Cell/ ITLL 30 mM $AgNO_3$, (b) Cell/ ITLL 50 mM $AgNO_3$

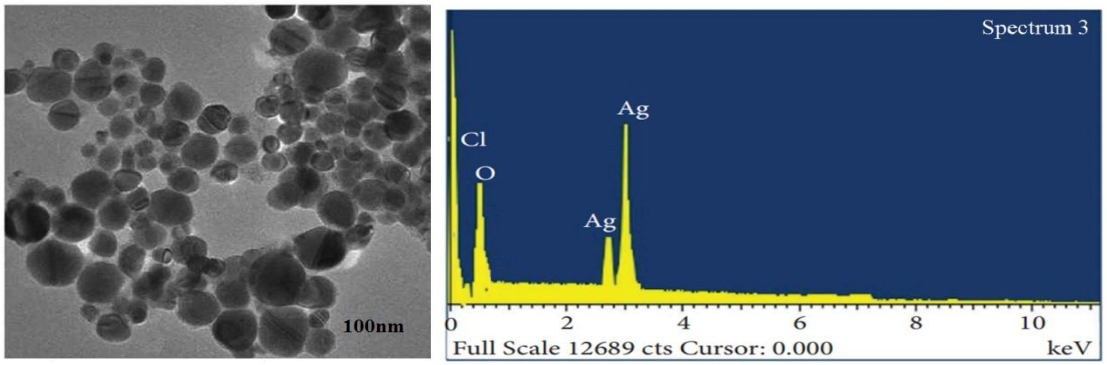

Fig.-5 and 6: TEM Image of Cell/ ITLL 50 mM $AgNO_3$and EDAX Spectra of Cell/ ITLL 50 mM $AgNO_3$

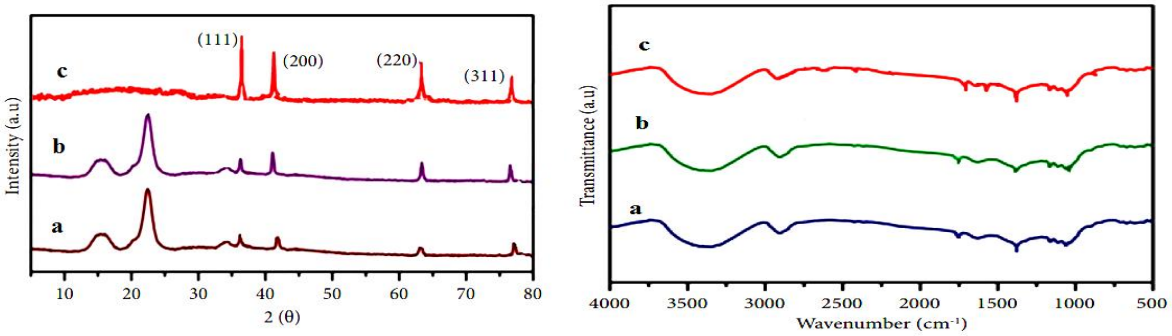

Fig.-7 and 8: XRD Spectra of 7(a) Cellulose, 7(b) Cell/ ITLL 50 mM $AgNO_3$, and 7(c) Ag NPs. and FTIR Spectra of 8(a) Cellulose, 8(b) XTLL, and 8(c) Cell/ ITLL 50 mM $AgNO_3$

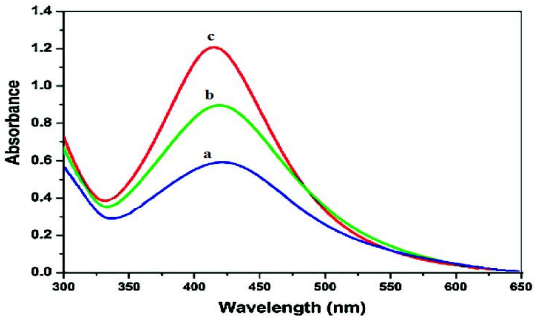

Fig.-9: UV Spectrum of (a) Initial Reaction Mixture, (b) Cell/ ITLL 30 mM $AgNO_3$, and (c) Cell/ ITLL 50 mM $AgNO_3$

Photocatalytic Activity Measurement

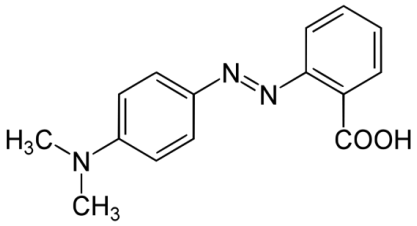

Fig.-10: Structure of Methyl Red Dye

The photocatalytic performance of the prepared nanocomposites, Cell/ITLL and Cell/ITLL–Ag (60 mM $AgNO_3$), was evaluated using Methyl Red (MR) as a model dye pollutant. For each trial, 0.05 g of photocatalyst was dispersed in 100 mL of MR solution (concentration: 1.05 gL^{-1}). The suspension was first sonicated for 15 minutes to achieve uniform dispersion, followed by equilibration under dark conditions for 60 minutes to establish adsorption–desorption equilibrium. Photocatalysis was carried out under natural solar irradiation using a custom-built opaque chamber designed to maximize light capture. Aliquots were withdrawn at specific time intervals and analyzed by UV–Vis spectroscopy, monitoring changes in absorbance at λ = 640 nm. The recyclability and stability of the photocatalysts were further assessed by conducting repeated degradation experiments using the Cell/ITLL–Ag (50 mM $AgNO_3$) sample.

Biological Activity

Antimicrobial activity was evaluated using standard microbiological assays. These assays operate on the principle that the growth inhibition zone produced by a test sample can be compared to that of a reference antibiotic with known potency. Two classical methods, namely the cup–plate method and the disc diffusion method, were employed. In the cup–plate method, the test solution diffuses through a solidified agar medium from a well or cavity, creating a zone of inhibition (ZOI) around the well where bacterial proliferation is suppressed. In this study, the antibacterial properties of Cellulose, Cell/ITLL, and Cell/ITLL–Ag composites (30 mM and 50 mM $AgNO_3$) were examined. The bacterial strains used for

evaluation are summarized in Table-1. Cultures were first grown in brain heart infusion (BHI) broth at 36–37 °C for 12 h to achieve active-phase growth. The microbial suspension was standardized to 1×10^6 CFU/mL (equivalent to 0.5 McFarland standard) and uniformly spread over Mueller–Hinton agar (MHA) plates before the application of test samples.

Table-1: Details of the Microorganism

S. No.	Name of Microorganism	MTCC No.
1	*Escherichia coli* (Gram –ve)	2692
2	*Pseudomonas aeruginosa* (Gram –ve)	2453
3	*Staphylococcus aureus* (Gram +ve	902
4	*Bacillus subtilis* (Gram +ve)	441

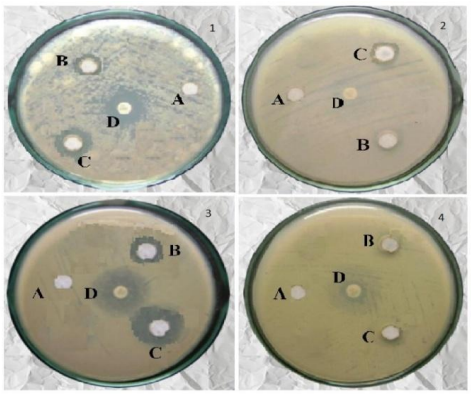

Fig.-11: Antibacterial Activity of Cellulose (A), Cell/ ITLL 30 mM $AgNO_3$(B), Cell/ ITLL 50 mM $AgNO_3$(C), and Positive Control Streptomycin (D). Bacteria Strains: *Escherichia coli (1), Pseudomonas aeruginosa (2), Staphylococcus aureus (3), Bacillus subtilis (4)*

RESULTS AND DISCUSSION

Morphological Analysis (SEM and EDAX)

The morphology of Cell/ITLL and Cell/ITL samples before and after $AgNO_3$treatment (30 and 50 mM) was examined by SEM (Fig.-4). The SEM images revealed the formation of spherical silver nanoparticles dispersed within the cellulose matrix. EDAX spectra (Fig.-6) confirmed the presence of Ag signals, further validating the successful incorporation of Ag nanoparticles in the Cell/ITLL nanocomposites.[13,30]

TEM Analysis

TEM images of Cell/ITLL treated with 60 mM $AgNO_3$ demonstrated the formation of spherical nanoparticles with an average size of ~32.65 nm (Fig.-5). The uniform morphology supports the SEM observations, confirming the controlled synthesis of Ag nanoparticles within the cellulose framework.

X-Ray Diffraction (XRD)

XRD spectra (Fig.-7) of cellulose, Ag nanoparticles, and Cell/ITLL–Ag composites revealed diffraction peaks at $2\theta = 38°$, 44°, 64°, and 77°, corresponding to the crystallographic planes (111), (200), (220), and (311) of face-centered cubic silver crystals. These results are in agreement with JCPDS Card Nos. 89-3722 and 87-0720, confirming the crystalline nature of the Ag nanoparticles.[31]

Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectra (Fig.-8) provided evidence of chemical interactions between cellulose and Ag nanoparticles. Characteristic bands were observed at 2258, 1719, 1625, 1557, and 1073 cm^{-1}, corresponding to C–O–C, C–O, and C=C groups. These bands are associated with phytochemicals such as quercetin-3-O-rhamnoside, kaempferol-3-O-rhamnoside, luteolin-7-O-glucoside, β-sterol, and stigmasterol, present in Ipomoea tridentata (L.) leaf extract.[16-18] The peak at 1730 cm^{-1} in the Cell/ITLL–50 mM $AgNO_3$ sample was attributed to C=O stretching, indicating the role of carbonyl groups in the reduction of Ag^+ ions. The abundant hydroxyl groups in cellulose further stabilised the nanoparticles through hydrogen bonding interactions.[13,31–33]

UV–Visible Spectroscopy

UV–Vis spectra (Fig.-9) of Cell/ITLL–Ag composites exhibited a surface plasmon resonance (SPR) band at 415–425 nm, characteristic of Ag nanoparticles. The increase in peak intensity with higher $AgNO_3$ concentration indicated a proportional rise in nanoparticle concentration.[13]

Absorption Spectral Analysis to Study Photo Degradation

Photocatalysis was carried out under natural solar irradiation using a custom-built opaque chamber designed to maximize light capture. The photocatalytic activity of Cell/ITLL 50 mM $AgNO_3$ was assessed through the degradation of methyl red (MR) dye and compared with that of untreated cellulose. The presence of well-dispersed Ag nanoparticles effectively suppressed electron–hole recombination, thereby enhancing photocatalytic efficiency and dye adsorption. Using 100 mg of the Cell/ITLL 50 mM $AgNO_3$ catalyst, a degradation efficiency of 85% for MR was achieved, highlighting its excellent potential for environmental and biomedical applications. Figure-12 exhibits the outcomes.

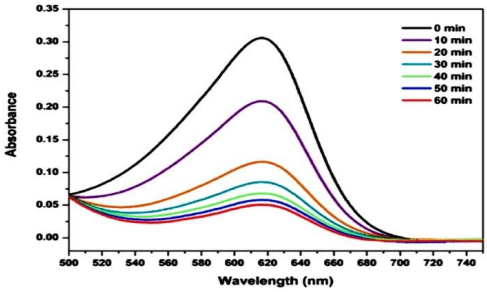

Fig.-12: UV-Visible Absorption Spectrum for the Degradation of MR dye at different Time Intervals

Recycling Ability of the Catalyst

The cost-effectiveness and stability of the photocatalyst are significantly enhanced by its ability to be recycled. After the degradation process was completed, the selected nanoparticles were separated from the test solution through centrifugation to evaluate their recyclability. The recovered nanoparticles were thoroughly washed with double-distilled water, filtered, dried, and reused in subsequent degradation cycles. This procedure was repeated for several cycles, and UV-Visible absorbance data revealed that the dye degradation efficiency remained nearly constant over five consecutive cycles. These results clearly demonstrate the excellent recycling capability of the synthesized nanoparticles (Table-2).

Antimicrobial Activity

The antimicrobial properties of cellulose and its nanocomposites were evaluated using disc diffusion assays (Fig.-11). Cell/ITLL–Ag composites showed significantly enhanced activity compared to pristine cellulose. The inhibitory effect increased with $AgNO_3$ concentration, with Cell/ITLL–50 mM $AgNO_3$ displaying the largest zone of inhibition (ZOI) against both Gram-positive (*Staphylococcus aureus, Bacillus subtilis*) and Gram-negative (*Escherichia coli, Pseudomonas aeruginosa*) bacteria.

Table-2: Photo Degradation of Dye Efficiency of Cell/ ITLL $AgNO_3$

Run No.	Degradation efficiency (%)
1	85
2	83
3	81
4	81
5	80

The enhanced antibacterial activity can be attributed to:

- Ag^+ ion release, disrupting DNA replication.
- Reactive oxygen species (ROS) generation, causing oxidative stress.
- Nanoparticle penetration into bacterial membranes, leading to cell lysis.[34–40]

Thus, Cell/ITLL–Ag nanocomposites, particularly at higher $AgNO_3$ concentrations, act as effective antimicrobial agents against pathogenic bacteria.

CONCLUSION

In conclusion, the present study demonstrates a green and sustainable strategy for synthesizing cellulose–silver nanocomposites using Ipomoea tridentata leaf extract as a natural reducing agent. The resulting Ag nanoparticles exhibited uniform distribution and effective structural integration within the cellulose matrix, leading to enhanced antibacterial and photocatalytic performance. Notably, the optimized composite showed strong activity against both Gram-positive and Gram-negative bacteria, along with efficient degradation of organic pollutants under visible light. These outcomes highlight the potential of plant-mediated nanomaterial synthesis as an environmentally responsible alternative to conventional methods. By reducing chemical usage, improving material efficiency, and enabling applications in water purification and antimicrobial systems, this work directly supports the goals of SDG 12: Responsible Consumption and Production, emphasizing sustainable production practices and the development of eco-friendly functional materials.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

The present work is related to *SDG-12: Responsible Consumption and Production*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

H. Usha http://orchid.org/0009-0007-3903-0054
D. Santhi Priya http://orchid.org/0009-0008-6372-6307
J. Chandrasekhar Rao http://orchid.org/0009-0001-7909-389X
P. Jaya Ranga Rao http://orchid.org/0000-0001-8561-1334
M. Sankara Rao http://orchid.org/0000-0001-7988-9022
Preetha Bhadra http://orchid.org/ 0000-0001-6445-013X
A. Satheesh http://orchid.org/0000-0001-9191-3179

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