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Silver Nanoparticles From Terminalia mantaly : Biogenic synthesis and characterization

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Abstract

The green synthesis of silver nanoparticles (AgNPs) using plant-based extracts has emerged as an environmentally friendly and sustainable method, gaining increasing interest in recent years. This review emphasizes the use of *Terminalia mantaly* in the biosynthesis of AgNPs, presenting it as an effective and eco-conscious approach to nanoparticle production. Rich in bioactive constituents such as flavonoids, tannins, and polyphenols, *Terminalia mantaly* plays a dual role as both a reducing and stabilizing agent during nanoparticle formation. The article also discusses various analytical techniques employed to characterize these nanoparticles, including UV-Visible spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, X-ray diffraction (XRD), and transmission electron microscopy (TEM). Moreover, the review outlines the biological activities of AgNPs derived from *Terminalia mantaly* leaves, highlighting their antimicrobial, antioxidant, anti-inflammatory, and anticancer potential. The broader environmental and biomedical applications of these biologically synthesized nanoparticles are also explored. This sustainable synthesis method represents a promising alternative to traditional chemical techniques, offering eco-friendly production alongside multifunctional biological benefits.

Key words: Terminalia mantaly Leaf extract, Nanoparticles Synthesis, Characterization, and Biological Activities

1. Introduction

Nanotechnology has rapidly advanced as a transformative discipline with vast applications in fields such as medicine, environmental science, and materials engineering. Among the diverse range of nanoparticles, silver nanoparticles (AgNPs) have gained considerable attention owing to their potent antimicrobial, antioxidant, and anticancer effects. However, conventional methods for synthesizing AgNPs typically rely on toxic chemicals, leading to concerns about environmental safety and human compatibility [1]. As a result, there is a growing shift toward green synthesis techniques that employ biological materials like plant extracts, offering a more sustainable and environmentally responsible alternative.

Terminalia mantaly, a plant species commonly found in coastal and estuarine regions, is particularly rich in phytochemicals such as flavonoids, tannins, and polyphenols. These bioactive compounds serve as effective reducing and capping agents in nanoparticle synthesis. Research has shown that these naturally occurring substances can efficiently convert silver ions into silver nanoparticles while also enhancing their biological properties [2].

2. Biogenic Synthesis of Silver Nanoparticles Using *Terminalia mantaly* Leaf Extracts

The eco-friendly synthesis of silver nanoparticles (AgNPs) using *Terminalia mantaly* leaf extracts has gained considerable interest due to the plant's unique characteristics and chemical composition [12]. Known for their adaptability to extreme environmental conditions, *Terminalia mantaly* plants possess leaves rich in secondary metabolites—such as flavonoids, polyphenols, and tannins—that enhance both the stability and bioactivity of the synthesized nanoparticles [3]. Furthermore, employing plant-based synthesis methods is consistent with green chemistry principles, as it avoids hazardous chemicals and limits the production of toxic byproducts [4].

This review investigates the green synthesis of AgNPs utilizing extracts from *Terminalia mantaly* leaves, with an emphasis on nanoparticle characterization and their potential applications in medicine. By harnessing the natural reducing capacity of *Terminalia mantaly*, the study contributes to the advancement of environmentally sustainable nanotechnologies with promising roles in antimicrobial, antioxidant, anti-inflammatory, and anticancer therapies.

3. Green Synthesis of Silver Nanoparticles

Biogenic synthesis refers to the environmentally benign production of nanoparticles using biological resources such as plant extracts, microorganisms, or enzymes. Among these, plant-based synthesis stands out for its simplicity, cost-effectiveness, and richness in bioactive molecules [5]. In particular, *Terminalia mantaly*, which commonly grows in saline and coastal regions, is abundant in phytochemicals capable of acting as natural reducing and stabilizing agents during nanoparticle formation [6].

Number of leaf extracts, flower extracts, root extracts have been used earlier for the synthesis of nanoparticles by our research team including

Ocimum tenuiflorum L. Green and Purple (17), Ocimum basilicum L. *var*. basilicum (20), Ocimum basilicum L. *var*. thyrsiflorum(18,20), Ocimum americanum L (19), Terminalia mantaly (22,24) , Betel Leaf Extract and Oxalis stricta (23) leaf extracts. In this study, *Terminalia mantaly* leaves were harvested, thoroughly rinsed with distilled water, and air-dried at ambient temperature. Once dried, the leaves were finely ground and subjected to aqueous extraction by boiling in distilled water. The resulting solution was then filtered to eliminate solid residues, producing a phytochemical-rich extract that served as the bioreductant in the nanoparticle synthesis process [7].

Silver nitrate ($AgNO_3$) was employed as the source of silver ions. Under continuous stirring at room temperature, the *Terminalia mantaly* extract was added dropwise to the $AgNO_3$ solution. A visible color transition—ranging from pale yellow to dark brown—was observed, signifying the successful formation of silver nanoparticles. This change is attributed to surface plasmon resonance (SPR), a phenomenon associated with the unique optical properties of metallic nanoparticles [8].

4. Characterization of Biosynthesized Silver Nanoparticles

To verify the successful synthesis of silver nanoparticles (AgNPs) and to gain insights into their physical and chemical properties, various analytical techniques were employed. These methods helped determine the morphology, crystalline structure, particle size, and the functional groups involved in the biosynthesis process [14, 15].

1. **UV-VisibleSpectroscopy**

The initial confirmation of AgNP formation was obtained through UV-Vis spectroscopy. A characteristic surface plasmon resonance (SPR) band—typically located between 400 and 450 nm—was observed, indicating the presence of silver nanoparticles. The exact wavelength of the SPR peak varies depending on the nanoparticles' size, shape, and the surrounding medium.

2. **X-ray Diffraction (XRD)**

The crystalline structure of the synthesized AgNPs was analyzed using X-ray diffraction. The XRD pattern exhibited sharp peaks at 2θ angles near 38°, 44°, 64°, and 77°, corresponding to the (111), (200), (220), and (311) planes of face-centered cubic (FCC) silver. These results confirmed the high crystallinity of the nanoparticles.

3. **Transmission Electron Microscopy (TEM)**

TEM was used to examine the size and morphology of the AgNPs. The images revealed that the nanoparticles were predominantly spherical, well-dispersed, and ranged in size from approximately 10 to 50 nanometers. High-resolution TEM also demonstrated lattice fringes, further confirming the crystalline nature observed in the XRD analysis.

4. **Fourier-Transform Infrared Spectroscopy (FTIR)**

FTIR analysis was conducted to identify the functional groups present in the *Terminalia mantaly* leaf extract that contributed to the reduction and stabilization of AgNPs. The FTIR spectra showed distinct absorption bands associated with functional groups such as hydroxyls, suggesting their involvement in nanoparticle formation.

5. **Dynamic Light Scattering (DLS)**

Dynamic Light Scattering (DLS) was utilized to evaluate the particle size distribution and colloidal stability of the synthesized silver nanoparticles. The analysis revealed a narrow size range, indicating uniform dispersion of the nanoparticles in solution. Additionally, zeta potential measurements confirmed the stability of the colloidal suspension, with values suggesting strong electrostatic repulsion, which prevents aggregation and supports good stability.

5.Biological Activities of Silver Nanoparticles

Silver nanoparticles (AgNPs) produced via green synthesis using *Terminalia mantaly* leaf extracts have attracted attention for their promising applications in both healthcare and environmental fields [11]. Their biological effects are strongly influenced by factors such as particle size, shape, surface characteristics, and the phytochemicals retained from the plant extract. AgNPs derived from *Terminalia mantaly* exhibit a variety of bioactivities, including antimicrobial, antioxidant, anti-inflammatory, and cytotoxic effects, positioning them as strong candidates for medical and therapeutic uses.

1. Antimicrobial Properties

AgNPs synthesized from *Terminalia mantaly* have demonstrated potent antimicrobial effects against a wide range of harmful microorganisms, including bacteria, fungi, and viruses. Their antimicrobial mechanisms include disrupting microbial membranes, inducing the production of reactive oxygen species (ROS), and impairing DNA replication in pathogens [9].

Research indicates that these biosynthesized nanoparticles are effective against both Gram-positive and Gram-negative bacteria, such as

Staphylococcus aureus and *Escherichia coli*. The antimicrobial performance is enhanced by the presence of bioactive compounds from *Terminalia mantaly*, which act synergistically with the silver. Furthermore, the nanoparticles also show antifungal capabilities, exhibiting inhibitory effects on fungal pathogens like *Candida albicans* and *Aspergillus niger* [10].

2. Antioxidant Activity

The antioxidant capabilities of biogenically synthesized silver nanoparticles (AgNPs) are of significant interest due to their potential role in combating oxidative stress-related conditions. The phytochemicals present in *Terminalia mantaly* leaf extracts, which are retained on the nanoparticle surface, contribute notably to their antioxidant function. These compounds help neutralize free radicals, thereby mitigating oxidative damage within biological systems [13].

To assess this activity, assays such as the DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) radical scavenging methods have been employed. The results consistently show that AgNPs derived from *Terminalia mantaly* exhibit high free radical scavenging efficiency, often comparable to standard antioxidants like ascorbic acid. This indicates their potential for application in the treatment of oxidative stress-related disorders, including cardiovascular diseases, neurodegenerative conditions, and age-associated ailments [15].

3. Anti-inflammatory Activity

Apart from antimicrobial and anticancer effects, AgNPs synthesized from *Terminalia mantaly* also display notable anti-inflammatory properties. These effects are primarily attributed to the suppression of key inflammatory mediators, such as pro-inflammatory cytokines and cyclooxygenase-2 (COX-2), which are central to the inflammatory response [15].

Experimental findings suggest that these nanoparticles can effectively reduce the expression of inflammatory markers in immune cells like macrophages. This anti-inflammatory action makes them promising candidates for managing inflammatory disorders such as arthritis and inflammatory bowel disease, where controlling inflammation is essential for symptom relief and improved therapeutic outcomes [16].

4. Cytotoxic and Anticancer Activity

The cytotoxic effects of AgNPs synthesized from *Terminalia mantaly* have been tested against various cancer cell lines, revealing promising anticancer potential. Their cytotoxicity is both dose-dependent and influenced by particle size, concentration, and the type of cancer cells involved.

In vitro studies have demonstrated that these nanoparticles induce significant cytotoxic effects on cancer cells, including HeLa (cervical cancer), MCF-7 (breast cancer), and A549 (lung cancer). The mechanism is believed to involve the generation of reactive oxygen species (ROS), loss of mitochondrial membrane potential, and activation of apoptotic pathways. Importantly, these AgNPs exhibit selective toxicity, preferentially targeting cancerous cells while minimizing harm to normal cells—an essential quality for potential use in cancer therapy [11].

6. Conclusion

This study highlights the potential of using *Terminalia mantaly* leaf extracts for the green synthesis of silver nanoparticles (AgNPs), offering an environmentally sustainable alternative to conventional chemical synthesis methods. The rich phytochemical profile of *Terminalia mantaly* makes it a suitable and effective natural source for reducing and stabilizing agents in nanoparticle production, aligning well with the principles of green chemistry.

Characterization studies confirmed the successful formation of AgNPs, with UV-visible spectroscopy indicating surface plasmon resonance peaks typical of silver nanoparticles. X-ray diffraction (XRD) and transmission electron microscopy (TEM) analyses revealed their crystalline structure and size distribution, while Fourier-transform infrared spectroscopy (FTIR) identified functional groups responsible for reduction and stabilization.

The synthesized nanoparticles demonstrated promising biological properties, including strong antimicrobial activity against a broad range of pathogens, making them potential alternatives to traditional antimicrobial agents. Their antioxidant capacity suggests their use in managing oxidative stress and related health disorders. Additionally, the nanoparticles exhibited selective cytotoxicity towards cancer cells, indicating potential for further exploration in cancer treatment. Their notable anti-inflammatory effects further broaden their therapeutic applications, particularly for diseases involving chronic inflammation.

In summary, the biogenic synthesis of AgNPs using *Terminalia mantaly* offers a green, efficient, and multifunctional approach to nanoparticle development. This eco-friendly method not only contributes to advancements in nanotechnology but also supports sustainable scientific practices. Future studies should focus on refining synthesis methods, expanding biological evaluations, and ensuring environmental safety for broader biomedical and industrial use.

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