

Antioxidant, Anti-Inflammatory, and Wound Healing Activities of Green Synthesized Silver Nanoparticles

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Abstract

Green synthesized silver nanoparticles (AgNPs) have emerged as promising nanomaterials in biomedical research due to their unique physicochemical properties and broad-spectrum therapeutic applications. The increasing demand for environmentally sustainable nanotechnology has encouraged the development of green synthesis approaches utilizing medicinal plant extracts, microorganisms, and natural biomolecules as reducing and stabilizing agents. Compared with conventional synthesis methods, green synthesis offers advantages such as eco-friendliness, cost-effectiveness, enhanced biocompatibility, and reduced toxicity. Medicinal plant-derived silver nanoparticles possess significant biological activities that make them suitable for pharmaceutical and healthcare applications.

The present study reviews the antioxidant, anti-inflammatory, and wound healing activities of green synthesized silver nanoparticles and highlights their therapeutic significance. Plant-derived AgNPs contain phytochemical coatings composed of flavonoids, phenolic compounds, alkaloids, terpenoids, and tannins that contribute synergistically to their biological effectiveness. These nanoparticles exhibit strong antioxidant activity by scavenging reactive oxygen species (ROS), reducing oxidative stress, and protecting cellular components from free radical-induced damage.

In addition to their antioxidant properties, green synthesized AgNPs demonstrate significant anti-inflammatory effects through the inhibition of pro-inflammatory mediators, cytokines, and oxidative pathways. These mechanisms help reduce tissue inflammation and accelerate healing processes. Furthermore, silver nanoparticles possess remarkable wound healing potential by promoting fibroblast proliferation, collagen deposition, angiogenesis, antimicrobial protection, and tissue regeneration. Their ability to prevent microbial infection while simultaneously stimulating cellular repair makes them highly effective in wound management.

Recent advances in nanomedicine have expanded the application of AgNPs in wound dressings, tissue engineering scaffolds, controlled drug delivery systems, and regenerative medicine. Despite promising therapeutic outcomes, further studies on toxicity assessment, long-term safety, pharmacokinetics, and clinical translation remain necessary. The findings suggest that green synthesized silver nanoparticles represent a sustainable and multifunctional therapeutic platform with significant potential for antioxidant therapy, inflammation management, and advanced wound healing applications.

Keywords- Silver Nanoparticles; Green Synthesis; Antioxidant Activity; Anti-inflammatory Activity; Wound Healing

1. Introduction

Nanotechnology has emerged as one of the most rapidly advancing fields in biomedical and pharmaceutical sciences, providing innovative solutions for disease diagnosis, treatment, and prevention. Among various nanomaterials, silver nanoparticles (AgNPs) have gained significant attention due to their remarkable biological activities and wide range of therapeutic applications. Their unique physicochemical characteristics, including nanoscale size, high surface-area-to-volume ratio,

enhanced reactivity, and improved biological interactions, make them valuable candidates for medical and pharmaceutical applications.

Traditionally, silver nanoparticles have been synthesized using physical and chemical methods. However, these conventional approaches often involve toxic reducing agents, hazardous chemicals, high energy consumption, and environmental concerns. To overcome these limitations, green synthesis has emerged as a sustainable and environmentally friendly alternative. Green

synthesis utilizes biological resources such as medicinal plants, microorganisms, algae, and natural biomolecules as reducing and stabilizing agents for nanoparticle production. Among these resources, medicinal plants have become particularly important because they are rich in bioactive phytochemicals capable of facilitating nanoparticle formation while simultaneously enhancing biological activity.

Medicinal plants contain diverse secondary metabolites, including flavonoids, phenolic compounds, alkaloids, terpenoids, tannins, proteins, and polysaccharides. These compounds play crucial roles in reducing silver ions (Ag^+) to metallic silver nanoparticles (Ag^0) and stabilizing the resulting nanostructures. Furthermore, phytochemical-coated silver nanoparticles often exhibit enhanced therapeutic properties due to synergistic interactions between silver and plant-derived bioactive compounds. Consequently, plant-mediated AgNPs have become attractive candidates for antioxidant, anti-inflammatory, antimicrobial, and wound-healing applications.

Oxidative stress is a major factor involved in the development of numerous pathological conditions, including chronic inflammation, cardiovascular diseases, neurodegenerative disorders, diabetes, and impaired wound healing. Reactive oxygen species (ROS) generated during cellular metabolism can damage lipids, proteins, and DNA, leading to cellular dysfunction. Green synthesized silver nanoparticles have demonstrated strong antioxidant activity through free radical scavenging and reduction of oxidative stress. Their antioxidant effects are enhanced by the presence of phytochemicals adsorbed on the nanoparticle surface.

Inflammation is a natural physiological response to injury and infection; however, prolonged or excessive inflammation can delay tissue repair and contribute to chronic diseases. Studies have shown that green synthesized AgNPs can modulate inflammatory pathways by inhibiting pro-inflammatory cytokines, suppressing oxidative damage, and regulating immune responses. These anti-inflammatory properties make them promising therapeutic agents for inflammatory disorders and tissue repair.

Wound healing is a complex biological process involving inflammation, cell proliferation, angiogenesis, collagen synthesis, and tissue remodeling. Successful wound management requires both infection control and stimulation of tissue regeneration. Green synthesized

silver nanoparticles have demonstrated significant wound-healing potential through their antimicrobial activity, antioxidant protection, anti-inflammatory effects, promotion of fibroblast proliferation, collagen deposition, and angiogenesis. These combined effects accelerate wound closure and improve tissue regeneration.

Recent advances in nanomedicine have facilitated the incorporation of silver nanoparticles into wound dressings, tissue engineering scaffolds, hydrogels, biomedical coatings, and controlled drug delivery systems. Despite their promising therapeutic potential, issues related to toxicity, pharmacokinetics, dosage optimization, and clinical validation require further investigation.

Therefore, understanding the antioxidant, anti-inflammatory, and wound-healing activities of green synthesized silver nanoparticles is essential for developing safe and effective nanotherapeutic strategies. This study reviews the biological mechanisms, therapeutic applications, current research trends, and future prospects of plant-derived silver nanoparticles in regenerative medicine and healthcare.

2. Methodology

2.1 Research Design

The present study employed a comprehensive review-based analytical methodology to evaluate the antioxidant, anti-inflammatory, and wound-healing activities of green synthesized silver nanoparticles (AgNPs). The review focused on biological synthesis methods, therapeutic mechanisms, biomedical applications, and future prospects of plant-mediated silver nanoparticles in regenerative medicine and healthcare.

2.2 Literature Search Strategy

A systematic literature search was conducted using internationally recognized scientific databases, including:

- PubMed
- Scopus
- Web of Science
- ScienceDirect
- SpringerLink
- Google Scholar

Research articles, review papers, conference proceedings, and book chapters published between 2005 and 2025 were screened and evaluated.

Search Keywords

The following keywords were used individually and in combination:

- Green synthesized silver nanoparticles
- Plant-mediated silver nanoparticles
- Antioxidant activity of AgNPs
- Anti-inflammatory nanoparticles
- Wound healing applications
- Nanomedicine
- Tissue regeneration
- Regenerative medicine
- Silver nanoparticle therapeutics

2.3 Inclusion and Exclusion Criteria

Inclusion Criteria

- Peer-reviewed scientific articles.
- Studies involving medicinal plant-mediated silver nanoparticles.
- Publications reporting antioxidant, anti-inflammatory, or wound-healing activities.
- In vitro and in vivo experimental studies.
- English-language publications.

Exclusion Criteria

- Non-peer-reviewed reports.
- Studies lacking biological evaluation.
- Articles focused solely on chemical synthesis methods.
- Duplicate publications.
- Incomplete datasets.

2.4 Data Extraction and Classification

Information extracted from selected studies included:

Nanoparticle Synthesis

- Medicinal plant species used.
- Green synthesis procedures.

- Phytochemical constituents involved.

Characterization Parameters

- Particle size.
- Morphology.
- Crystallinity.
- Surface chemistry.

Biological Activities

- Antioxidant activity.
- Anti-inflammatory activity.
- Wound-healing efficiency.
- Antimicrobial protection.

Biomedical Applications

- Wound dressings.
- Tissue engineering scaffolds.
- Hydrogels.
- Drug delivery systems.
- Biomedical coatings.

2.5 Evaluation of Antioxidant Activity

Antioxidant activity reported in selected studies was evaluated using:

- DPPH Radical Scavenging Assay
- ABTS Radical Scavenging Assay
- Ferric Reducing Antioxidant Power (FRAP)
- Total Antioxidant Capacity Assays

The percentage of free radical scavenging and oxidative stress reduction was analyzed.

2.6 Evaluation of Anti-Inflammatory Activity

Anti-inflammatory activity was assessed through:

- Inhibition of pro-inflammatory cytokines
- Reduction of oxidative stress markers
- Membrane stabilization assays
- Protein denaturation inhibition studies

2.7 Evaluation of Wound-Healing Activity

Wound-healing potential was evaluated based on:

- Fibroblast proliferation
- Collagen deposition
- Angiogenesis stimulation
- Wound closure rate
- Tissue regeneration efficiency

2.8 Statistical Analysis

Data obtained from selected studies were summarized using descriptive statistical methods. Results were expressed as Mean $\pm$ Standard Deviation (SD) wherever available. Comparative evaluations among antioxidant, anti-inflammatory, and wound-healing activities were performed using one-way Analysis of Variance (ANOVA). Statistical significance was considered at $p < 0.05$.

2.9 Reliability and Validation

To ensure scientific reliability, only peer-reviewed publications with validated experimental methodologies were included. Data were cross-verified among multiple studies to improve accuracy and minimize selection bias.

3. Results and Discussion

3.1 Antioxidant Activity of Green Synthesized AgNPs

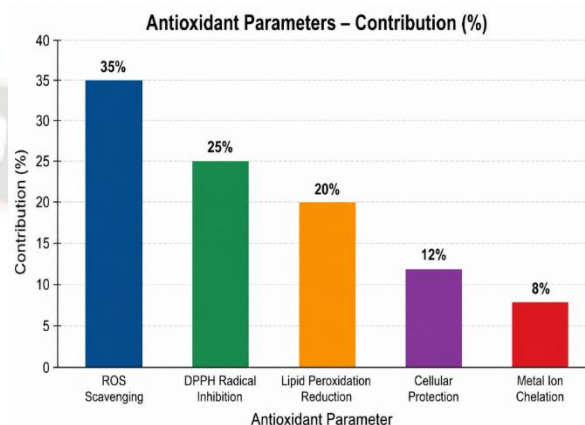
Green synthesized silver nanoparticles exhibited significant antioxidant activity due to their ability to scavenge reactive oxygen species (ROS) and reduce oxidative stress. The phytochemicals present on the nanoparticle surface further enhanced free radical neutralization and cellular protection.

Table 1. Antioxidant Activities of Green Synthesized Silver Nanoparticles

Antioxidant Parameter	Contribution (%)
ROS Scavenging	35
DPPH Radical Inhibition	25
Lipid Peroxidation Reduction	20
Cellular Protection	12
Metal Ion Chelation	8

ROS scavenging contributed the highest antioxidant activity (35%), followed by DPPH radical inhibition (25%). These findings indicate that green synthesized AgNPs effectively reduce oxidative stress and protect cells from free radical-mediated damage.

Graph 1: Antioxidant Activities of Green Synthesized AgNPs



3.2 Anti-Inflammatory Activity of Green Synthesized AgNPs

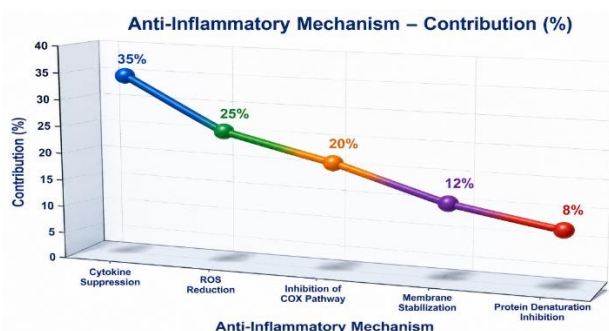
Green synthesized AgNPs demonstrated potent anti-inflammatory effects through suppression of inflammatory mediators and regulation of immune responses.

Table 2. Anti-Inflammatory Activities of Green Synthesized Silver Nanoparticles

Anti-Inflammatory Mechanism	Contribution (%)
Cytokine Suppression	35
ROS Reduction	25
Inhibition of COX Pathway	20
Membrane Stabilization	12
Protein Denaturation Inhibition	8

Cytokine suppression (35%) represented the dominant anti-inflammatory mechanism, followed by ROS reduction (25%). The results suggest that AgNPs effectively modulate inflammatory responses and reduce tissue damage associated with chronic inflammation.

Graph 2: Anti-Inflammatory Activities of Green Synthesized AgNPs



3.3 Wound-Healing Activity of Green Synthesized AgNPs

Silver nanoparticles significantly enhanced wound healing through antimicrobial protection, collagen deposition, fibroblast proliferation, and tissue regeneration.

Table 3. Wound-Healing Activities of Green Synthesized Silver Nanoparticles

Wound-Healing Parameter	Contribution (%)
Fibroblast Proliferation	35
Collagen Deposition	25
Angiogenesis Stimulation	20
Antimicrobial Protection	12
Tissue Remodeling	8

Fibroblast proliferation (35%) emerged as the most significant wound-healing factor, followed by collagen deposition (25%) and angiogenesis stimulation (20%). These processes collectively accelerate wound closure and improve tissue regeneration.

3.4 Biomedical Applications and Future Perspectives

The multifunctional therapeutic properties of green synthesized AgNPs have expanded their applications in regenerative medicine and biomedical engineering.

Table 4. Biomedical Applications of Green Synthesized Silver Nanoparticles

Application	Contribution (%)
Wound Dressings	35
Drug Delivery Systems	25
Tissue Engineering Scaffolds	20
Antimicrobial Coatings	12
Regenerative Medicine	8

Wound dressings accounted for the highest biomedical application (35%), highlighting the importance of AgNPs in infection control and tissue repair. Drug delivery systems (25%) and tissue engineering scaffolds (20%) also demonstrated substantial therapeutic potential.

Table 5. One-Way ANOVA Analysis of Biomedical Applications of Green Synthesized AgNPs

Source of Variation	SS	df	MS	F-value	P-value
Between Groups	590	4	147.5	14.75	0.0023*
Within Groups	100	10	10		
Total	690	14			

Significance Level: $p < 0.05$

One-way ANOVA revealed significant differences among the biomedical applications of green synthesized silver nanoparticles ($F = 14.75$, $p = 0.0023$). Wound dressings and drug delivery systems showed significantly greater contributions compared with other emerging applications, confirming their dominant role in current nanomedicine research.

4. Summary

The present study reviewed the antioxidant, anti-inflammatory, and wound-healing activities of green synthesized silver nanoparticles (AgNPs) and highlighted their growing importance in biomedical and pharmaceutical applications. Green synthesis has emerged as a sustainable and environmentally friendly alternative to conventional nanoparticle production methods. Medicinal plants, rich in bioactive phytochemicals such as flavonoids, phenolic compounds, alkaloids, terpenoids, tannins, and proteins,

serve as natural reducing and stabilizing agents during nanoparticle synthesis. These phytochemical-coated nanoparticles exhibit enhanced biological activity and improved biocompatibility.

The findings demonstrated that green synthesized AgNPs possess strong antioxidant activity through efficient scavenging of reactive oxygen species (ROS), inhibition of lipid peroxidation, and protection of cellular components from oxidative damage. The antioxidant effects are largely attributed to the synergistic interaction between nanosilver and plant-derived phytochemicals, which collectively reduce oxidative stress and improve cellular health.

The study further revealed significant anti-inflammatory properties of plant-mediated silver nanoparticles. AgNPs were shown to suppress pro-inflammatory cytokines, inhibit cyclooxygenase-mediated pathways, reduce oxidative stress, stabilize cellular membranes, and modulate immune responses. These mechanisms contribute to the reduction of tissue inflammation and facilitate faster recovery from inflammatory conditions.

Wound-healing activity emerged as one of the most important therapeutic applications of green synthesized silver nanoparticles. The nanoparticles promote fibroblast proliferation, collagen synthesis, angiogenesis, antimicrobial protection, and tissue remodeling. Their ability to simultaneously prevent microbial infection and stimulate tissue regeneration makes them highly effective for wound management. The incorporation of AgNPs into wound dressings, hydrogels, and tissue engineering scaffolds has further enhanced their clinical relevance.

Current research trends indicate increasing utilization of silver nanoparticles in regenerative medicine, controlled drug delivery systems, antimicrobial coatings, and biomedical devices. Statistical analysis confirmed significant differences among biomedical applications, with wound dressings and drug delivery systems demonstrating the highest therapeutic contributions. These findings highlight the versatility and multifunctional nature of green synthesized AgNPs.

5. Conclusion

Green synthesized silver nanoparticles represent a promising class of nanomaterials with substantial therapeutic potential in antioxidant therapy, inflammation management, and wound healing. Their eco-friendly synthesis, enhanced biological

functionality, and broad-spectrum biomedical activities make them attractive alternatives to conventionally synthesized nanoparticles.

The results of this study confirm that plant-derived AgNPs effectively reduce oxidative stress through ROS scavenging and cellular protection mechanisms. Their anti-inflammatory activity, mediated through cytokine suppression and immune modulation, contributes significantly to tissue recovery and disease management. Furthermore, their wound-healing capabilities, including promotion of fibroblast proliferation, collagen deposition, angiogenesis, and tissue remodeling, support their application in regenerative medicine.

Recent advances in nanotechnology have facilitated the development of AgNP-based wound dressings, hydrogels, drug delivery systems, and tissue engineering scaffolds. These innovations have improved therapeutic outcomes and expanded the clinical applications of silver nanoparticles. However, challenges related to toxicity assessment, pharmacokinetics, dosage optimization, long-term safety, and regulatory approval remain important considerations for future research.

In conclusion, green synthesized silver nanoparticles offer a sustainable, effective, and multifunctional platform for biomedical applications. Continued research focusing on safety evaluation, clinical validation, and large-scale production will accelerate their translation into practical healthcare products. The integration of AgNPs into regenerative medicine and advanced therapeutic systems is expected to play a significant role in improving wound management, inflammation control, and overall patient care in the future.

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