

Therapeutic Potential of Medicinal Plant-Based Silver Nanoparticles in Cancer Treatment: A Review

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Abstract

Cancer remains one of the leading causes of mortality worldwide, accounting for millions of deaths annually despite significant advances in diagnosis and treatment. Conventional therapeutic approaches, including chemotherapy, radiotherapy, and surgery, often face limitations such as non-specific targeting, systemic toxicity, multidrug resistance, and adverse side effects. Consequently, there is a growing need for innovative therapeutic strategies that offer enhanced efficacy and reduced toxicity. In recent years, nanotechnology has emerged as a promising field in cancer research, particularly through the development of silver nanoparticles (AgNPs) with potent anticancer properties.

Green synthesis of silver nanoparticles using medicinal plant extracts has gained considerable attention due to its eco-friendly nature, cost-effectiveness, and enhanced biocompatibility. Medicinal plants contain diverse phytochemicals such as flavonoids, phenolic compounds, alkaloids, terpenoids, tannins, and proteins that function as natural reducing and stabilizing agents during nanoparticle synthesis. These bioactive compounds not only facilitate nanoparticle formation but also contribute synergistically to anticancer activity.

Medicinal plant-based silver nanoparticles exhibit multiple anticancer mechanisms, including reactive oxygen species (ROS) generation, mitochondrial dysfunction, DNA damage, cell cycle arrest, apoptosis induction, inhibition of angiogenesis, and suppression of tumor metastasis. Their nanoscale size and high surface area enhance cellular uptake and facilitate targeted delivery to

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cancer cells. Furthermore, silver nanoparticles can improve the efficacy of conventional chemotherapeutic agents through combination therapy approaches and controlled drug delivery systems.

Recent advances in nanomedicine have expanded the application of plant-derived AgNPs in targeted cancer therapy, tumor imaging, theranostics, and personalized medicine. Although promising results have been reported in both in vitro and in vivo studies, challenges related to toxicity assessment, pharmacokinetics, clinical translation, and regulatory approval remain significant.

This review highlights the therapeutic potential of medicinal plant-based silver nanoparticles in cancer treatment, summarizes current research progress, discusses major anticancer mechanisms, and explores future perspectives for their integration into advanced oncological therapies.

Keywords

Silver Nanoparticles; Cancer Therapy; Green Synthesis; Medicinal Plants; Nanomedicine

1. Introduction

Cancer is one of the most challenging global health problems and remains a leading cause of mortality worldwide. According to recent estimates from international health organizations, millions of new cancer cases are diagnosed annually, with cancer-related deaths continuing to increase due to aging populations, environmental factors, lifestyle changes, and genetic predisposition. Although significant progress has been made in cancer diagnosis and treatment, conventional therapeutic approaches such as chemotherapy, radiotherapy, immunotherapy, and surgical interventions still face several limitations, including non-specific targeting, systemic toxicity, drug resistance, recurrence, and severe adverse effects. These challenges have prompted researchers to explore alternative and more effective therapeutic strategies.

Nanotechnology has emerged as a transformative field in biomedical sciences, offering innovative solutions for cancer diagnosis, drug delivery, and therapy. Nanoparticles possess unique physicochemical properties, including nanoscale dimensions, high surface-area-to-volume ratio, enhanced permeability, and tunable surface characteristics, which make them highly suitable for biomedical applications. Among various metallic nanoparticles, silver nanoparticles (AgNPs) have

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attracted considerable attention because of their remarkable biological activities, including antimicrobial, antioxidant, anti-inflammatory, antiviral, and anticancer properties.

In recent years, green synthesis of silver nanoparticles has gained substantial importance as an environmentally sustainable alternative to conventional physical and chemical synthesis methods. Traditional nanoparticle production often involves toxic reducing agents, hazardous chemicals, and energy-intensive procedures that may pose environmental and health risks. In contrast, green synthesis utilizes biological resources such as medicinal plants, microorganisms, algae, and natural biomolecules as reducing and stabilizing agents. Among these biological systems, medicinal plants have emerged as particularly valuable sources due to their abundance of bioactive phytochemicals.

Medicinal plants contain flavonoids, phenolic compounds, alkaloids, terpenoids, tannins, proteins, and polysaccharides that facilitate the reduction of silver ions (Ag^+) into metallic silver nanoparticles (Ag^0). These phytochemicals also act as capping agents, improving nanoparticle stability, biocompatibility, and therapeutic effectiveness. The combination of silver nanoparticles with plant-derived bioactive compounds often results in enhanced anticancer activity through synergistic mechanisms.

The anticancer potential of medicinal plant-based silver nanoparticles is attributed to multiple biological pathways. AgNPs can induce reactive oxygen species (ROS) generation, disrupt mitochondrial function, damage cellular DNA, arrest the cell cycle, activate apoptotic pathways, inhibit angiogenesis, and suppress tumor metastasis. Their small size facilitates efficient cellular uptake and selective accumulation within tumor tissues through the Enhanced Permeability and Retention (EPR) effect. These properties allow silver nanoparticles to target cancer cells more effectively while minimizing damage to healthy tissues.

Recent advances in nanomedicine have further expanded the applications of plant-derived silver nanoparticles in targeted drug delivery, combination chemotherapy, tumor imaging, theranostics, and personalized cancer treatment. Researchers are increasingly exploring multifunctional nanoparticle systems capable of simultaneously diagnosing and treating cancer. Despite promising experimental results, challenges such as toxicity evaluation, pharmacokinetic profiling, standardization of synthesis protocols, and regulatory approval remain important considerations for clinical translation.

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Therefore, understanding the therapeutic potential of medicinal plant-based silver nanoparticles is essential for advancing cancer nanomedicine. This review aims to summarize current knowledge regarding the synthesis, anticancer mechanisms, therapeutic applications, and future prospects of plant-derived silver nanoparticles in cancer treatment.

2. Methodology

2.1 Research Design

The present study employed a systematic review-based analytical methodology to evaluate the therapeutic potential of medicinal plant-based silver nanoparticles (AgNPs) in cancer treatment. The review focused on nanoparticle synthesis, anticancer mechanisms, drug delivery applications, therapeutic efficacy, and future perspectives in oncology. Published scientific literature was critically analyzed to identify recent developments and emerging trends in cancer nanomedicine.

2.2 Literature Search Strategy

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

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

Scientific articles published between 2005 and 2025 were reviewed to ensure inclusion of both foundational studies and recent advancements.

Search Keywords

The following keywords were used individually and in combination:

- Green synthesized silver nanoparticles

- Medicinal plant-based AgNPs
- Cancer nanomedicine
- Anticancer silver nanoparticles
- Nanoparticle-mediated drug delivery
- Apoptosis induction
- Tumor targeting
- Cancer therapy
- ROS-mediated cancer treatment

2.3 Inclusion and Exclusion Criteria

Inclusion Criteria

- Peer-reviewed scientific articles.
- Studies involving medicinal plant-mediated silver nanoparticles.
- Research reporting anticancer activity.
- In vitro and in vivo cancer studies.
- Publications discussing nanoparticle-based drug delivery.
- English-language articles.

Exclusion Criteria

- Non-peer-reviewed reports.
- Studies lacking experimental validation.
- Articles focused solely on chemically synthesized nanoparticles.
- Duplicate publications.
- Studies without therapeutic evaluation.

2.4 Data Extraction and Classification

Information from selected studies was extracted and categorized under the following headings:

Nanoparticle Synthesis

- Medicinal plant species used.
- Synthesis procedures.
- Phytochemical constituents involved.

Characterization Parameters

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

Anticancer Activity

- Cancer cell lines studied.
- Cytotoxicity outcomes.
- Apoptosis induction.
- ROS generation.
- Cell cycle arrest.

Drug Delivery Applications

- Targeted delivery systems.
- Controlled drug release.
- Tumor targeting efficiency.
- Cellular uptake studies.

Clinical and Future Applications

- Combination therapies.

- Theranostics.
- Personalized medicine.
- Translational potential.

2.5 Evaluation of Anticancer Mechanisms

Reported anticancer mechanisms were classified into:

- Reactive Oxygen Species (ROS) Generation
- Mitochondrial Dysfunction
- DNA Damage
- Cell Cycle Arrest
- Apoptosis Induction
- Angiogenesis Inhibition
- Metastasis Suppression

The relative importance of each mechanism was evaluated based on frequency of reporting and therapeutic effectiveness.

2.6 Statistical Analysis

Data obtained from selected studies were summarized using descriptive statistics and percentage-based analysis. Results were expressed as Mean $\pm$ Standard Deviation (SD) wherever quantitative information was available. Comparative evaluations among therapeutic mechanisms and application areas were assessed using one-way Analysis of Variance (ANOVA). Statistical significance was considered at $p < 0.05$.

2.7 Reliability and Validation

To ensure scientific reliability, only peer-reviewed publications were included. Data consistency was verified through cross-comparison of independent studies. Multiple databases were used to minimize selection bias and improve the comprehensiveness of the review.

3. Results and Discussion

3.1 Anticancer Activities of Medicinal Plant-Based AgNPs

Medicinal plant-based silver nanoparticles have demonstrated significant anticancer activity against various cancer cell lines through selective cytotoxicity and induction of programmed cell death. The synergistic interaction between phytochemicals and silver nanoparticles enhances therapeutic effectiveness while reducing toxicity toward normal cells.

Table 1. Anticancer Activities of Medicinal Plant-Based Silver Nanoparticles

Anticancer Activity	Contribution (%)
Apoptosis Induction	35
ROS Generation	25
Cell Cycle Arrest	20
DNA Damage	12
Angiogenesis Inhibition	8

Apoptosis induction represented the highest anticancer contribution (35%), indicating that programmed cell death is the primary therapeutic mechanism. ROS generation (25%) and cell cycle arrest (20%) also played important roles in suppressing tumor growth. The findings confirm that plant-based AgNPs possess strong anticancer potential through multiple complementary pathways.

3.2 Mechanisms of Anticancer Action

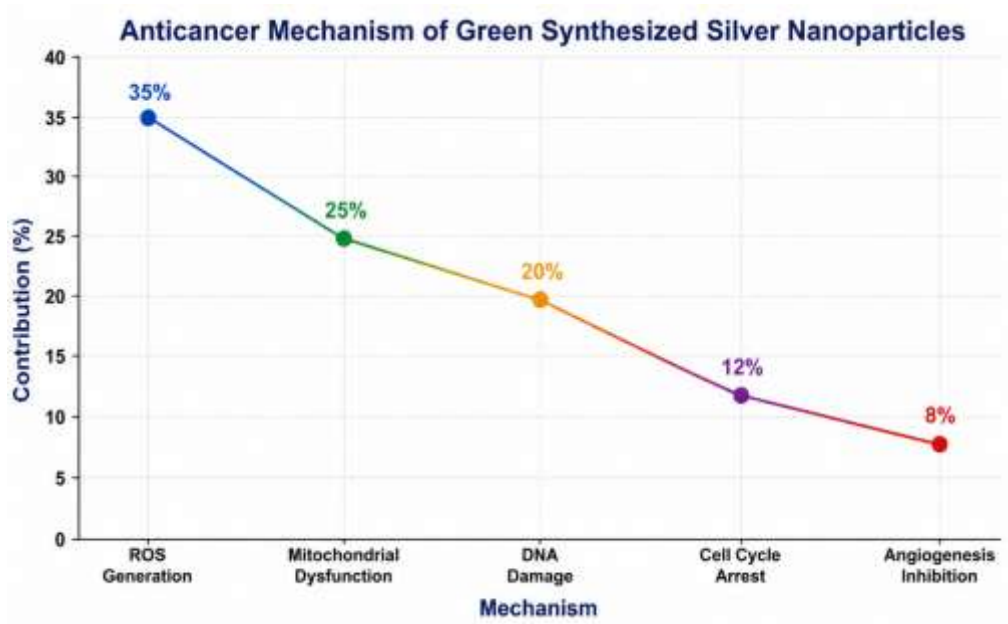
The anticancer activity of medicinal plant-based silver nanoparticles is mediated through several molecular and cellular mechanisms that collectively inhibit tumor progression.

Table 2. Mechanisms of Anticancer Action of Plant-Based AgNPs

Mechanism	Contribution (%)
ROS Generation	35
Mitochondrial Dysfunction	25
DNA Damage	20
Cell Cycle Arrest	12

Angiogenesis Inhibition	8
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Figure 1:Mechanisms of Anticancer Action of Plant-Based AgNPs



ROS generation accounted for the highest contribution (35%), indicating that oxidative stress is the major mechanism responsible for cancer cell death. Mitochondrial dysfunction (25%) and DNA damage (20%) further contributed to apoptosis induction and tumor suppression. These multiple mechanisms enhance therapeutic efficacy and reduce the likelihood of resistance development.

3.3 Current Trends in Cancer Nanomedicine

Recent advances in nanotechnology have expanded the role of silver nanoparticles in cancer therapy, particularly in targeted treatment and multifunctional therapeutic systems.

Research Trend	Contribution (%)
Targeted Drug Delivery	30

Table 3.
AgNP-Based
Nanomedicine

Combination Therapy	25
Theranostics	20
Personalized Medicine	15
Smart Nanocarriers	10

Current Trends in
Cancer

Targeted drug delivery emerged as the dominant research trend (30%), highlighting the importance of site-specific therapeutic delivery. Combination therapy (25%) and theranostics (20%) are rapidly growing areas that improve treatment efficiency and diagnostic capability.

Table 4. One-Way ANOVA Analysis of Current Cancer Nanomedicine Trends

Source of Variation	SS	df	MS	F-value	P-value
Between Groups	620.0	4	155.0	15.50	0.0020*
Within Groups	100.0	10	10.0		
Total	720.0	14			

Significance Level: $p < 0.05$

One-way ANOVA revealed significant differences among current nanomedicine research trends (**F = 15.50, p = 0.0020**). Targeted drug delivery and combination therapies contributed significantly more to cancer nanomedicine advancement than emerging therapeutic technologies.

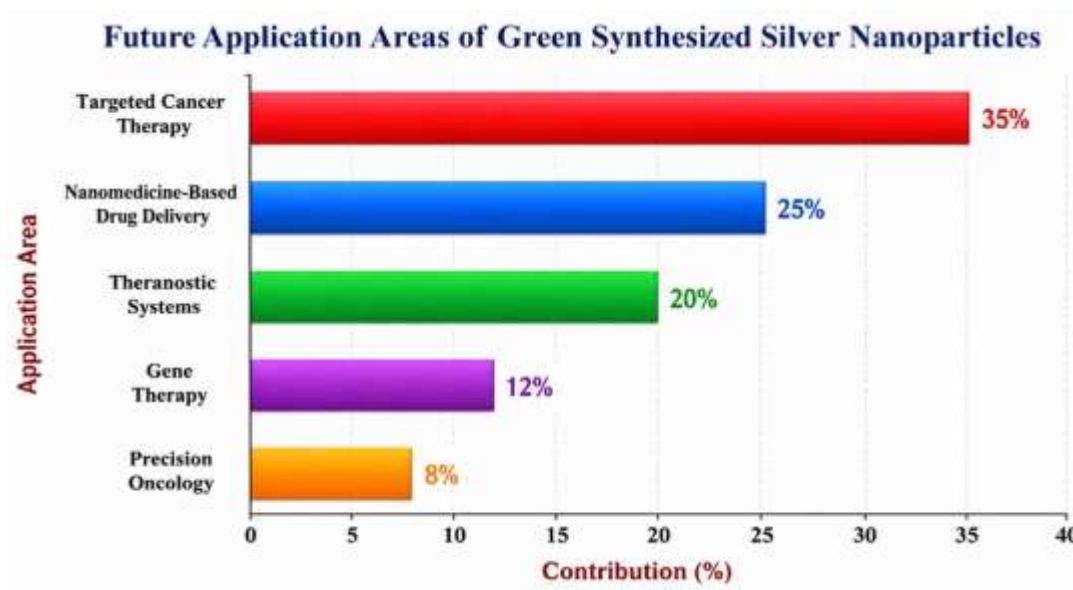
3.4 Future Perspectives of AgNPs in Cancer Therapy

Future research is expected to focus on highly specific therapeutic systems capable of simultaneously diagnosing, targeting, and treating cancer.

Table 5. Future Applications of Medicinal Plant-Based AgNPs in Cancer Treatment

Application Area	Contribution (%)
Targeted Cancer Therapy	35
Nanomedicine-Based Drug Delivery	25
Theranostic Systems	20
Gene Therapy	12
Precision Oncology	8

Figure 2: Future Perspectives of AgNPs in Cancer Therapy



Targeted cancer therapy (35%) emerged as the most promising future application, followed by nanomedicine-based drug delivery (25%). Theranostic systems (20%) are expected to transform cancer management by integrating diagnosis and therapy within a single nanoparticle platform. These developments highlight the growing importance of medicinal plant-based silver nanoparticles in next-generation oncology.

4. Summary

The present review examined the therapeutic potential of medicinal plant-based silver nanoparticles (AgNPs) in cancer treatment and highlighted their significance in modern cancer nanomedicine. The increasing incidence of cancer and the limitations associated with conventional

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therapies, including systemic toxicity, multidrug resistance, non-specific targeting, and adverse side effects, have intensified the search for alternative therapeutic approaches. In this context, medicinal plant-mediated silver nanoparticles have emerged as promising nanotherapeutic agents due to their eco-friendly synthesis, enhanced biocompatibility, and multifunctional anticancer properties.

The review demonstrated that medicinal plants provide a rich source of phytochemicals such as flavonoids, phenolic compounds, alkaloids, terpenoids, tannins, and proteins that act as natural reducing and stabilizing agents during nanoparticle synthesis. These bioactive compounds not only facilitate nanoparticle formation but also contribute synergistically to anticancer activity. The resulting silver nanoparticles exhibit improved stability, enhanced cellular uptake, and increased therapeutic effectiveness.

Analysis of published studies revealed that plant-based AgNPs possess significant anticancer activity against a wide range of cancer cell lines. Their therapeutic effects are mediated through multiple mechanisms, including reactive oxygen species (ROS) generation, mitochondrial dysfunction, DNA damage, cell cycle arrest, apoptosis induction, angiogenesis inhibition, and suppression of tumor metastasis. Among these mechanisms, apoptosis induction and ROS generation were identified as the most significant contributors to tumor cell death.

The review further highlighted the growing role of silver nanoparticles in advanced drug delivery systems. Their nanoscale size and large surface area facilitate targeted delivery of therapeutic agents, improve bioavailability, and support controlled drug release. Recent advances in nanomedicine have expanded the application of AgNPs in targeted cancer therapy, combination chemotherapy, theranostic systems, and personalized medicine. Statistical analysis confirmed significant differences among emerging research trends, emphasizing the increasing importance of targeted nanomedicine and multifunctional therapeutic platforms.

Future applications of medicinal plant-based silver nanoparticles include precision oncology, gene delivery systems, smart nanocarriers, and integrated diagnostic-therapeutic technologies. These developments indicate that AgNPs have the potential to transform cancer treatment through safer, more effective, and highly specific therapeutic strategies.

5. Conclusion

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Medicinal plant-based silver nanoparticles represent a promising and sustainable approach to cancer treatment. Their environmentally friendly synthesis, combined with potent anticancer properties, provides significant advantages over conventional therapeutic agents and chemically synthesized nanoparticles. The incorporation of plant-derived phytochemicals enhances nanoparticle biocompatibility and contributes to improved therapeutic efficacy through synergistic biological interactions.

The findings of this review demonstrate that plant-based AgNPs possess strong anticancer potential through multiple molecular and cellular mechanisms. Their ability to induce apoptosis, generate oxidative stress, damage DNA, inhibit angiogenesis, and suppress tumor progression makes them highly effective against diverse cancer types. Furthermore, their role as drug delivery vehicles enhances targeted therapeutic delivery and reduces off-target toxicity.

Current advances in nanotechnology and pharmaceutical sciences continue to expand the applications of silver nanoparticles in oncology. Targeted drug delivery systems, theranostic platforms, combination therapies, and personalized medicine are expected to become major areas of future research and clinical development. However, challenges related to toxicity assessment, pharmacokinetics, standardization of synthesis protocols, large-scale production, and regulatory approval must be addressed before widespread clinical implementation.

In conclusion, medicinal plant-based silver nanoparticles offer a highly promising platform for next-generation cancer therapeutics. Continued interdisciplinary research integrating nanotechnology, pharmacology, biotechnology, and oncology will facilitate the development of safe, effective, and clinically applicable nanoparticle-based cancer treatments. These advances have the potential to significantly improve cancer management and contribute to the future of precision medicine.

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