

From Plant Extracts to Nanomedicine: A Review on Green Silver Nanoparticle Synthesis and Characterization

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ABSTRACT

Silver nanoparticles (AgNPs) have been undeniably one of the most extensively discussed topics in the field of nanotechnology due to their fantastic physicochemical properties and potential for biomedical applications. Among various ways of synthesis, green synthesis using plant extracts has become one of the main alternatives to physical and chemical methods not only because of being environment-friendly but also due to being cheaper and more sustainable. The review thoroughly examines the green synthesis of AgNPs, particularly from *Ficus racemosa*. This involves the use of phytochemicals such as phenolics flavonoids alkaloids, and proteins which reduce and stabilize silver ions to produce nanoparticles. Moreover, it describes major nanoparticle characterization methods including UV-Visible spectroscopy, Fourier Transform Infrared (FTIR) analysis, Field Emission Scanning Electron Microscopy (FESEM), and Energy Dispersive Spectroscopy (EDS) that reveal nanoparticle formation size morphology, and composition. Importantly, the review also explores various biomedical applications of AgNPs that include antimicrobial antifungal antiviral, anticancer, and anti-inflammatory activities. Besides improved safety and increased biological activity, plant mediated AgNPs also provide a. Furthermore, it talks about the problems encountered and also presents some points for future investigation such as developing standard synthesis methods and expanding the study of antimicrobial products.

Keywords: Silver nanoparticles, Green synthesis, *Ficus racemosa*, Phytochemicals, Biomedical applications.

Introduction

Nanotechnology is a fast-evolving field of science that focuses on the design, manipulation, and use of materials at the nano scale (1-100 nm), where

materials exhibit unique physicochemical properties [3].

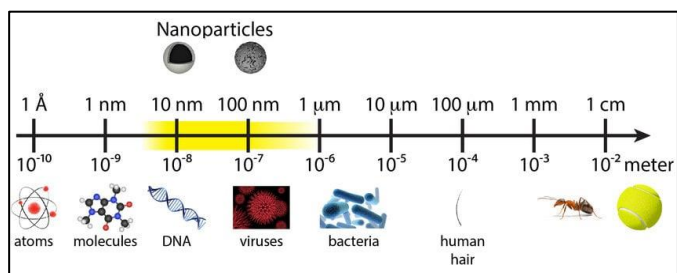


Fig.1 Nanotechnology Scale[source]

At these dimensions, materials show a larger surface area, higher reactivity, and new optical, electrical, and biological features. Silver nanoparticles (AgNPs) are a subset of metal-based nanoparticles which have gathered lots of interest due to their outstanding biological effects and their wide range of applications. AgNPs exhibit features that make them suitable for use in the biomedical, environmental, and industrial fields. They are effective antimicrobial antifungal antiviral, antioxidant, and anticancer agents [5], [7], [25]. These nanoparticles can multi-target microbial cells leading to actions like membrane damage, production of reactive oxygen species (ROS), interference with cellular mechanisms, resulting in their remarkable biological efficacy [26]. Due to those properties, AgNPs have been employed in various applications including drug delivery systems biosensors wound healing, and therapy of diseases [33]. Traditional ways of making silver nanoparticles, whether by physical or chemical methods, require a lot of energy and involve the use of expensive equipment and toxic chemicals. This leads to environmental and health problems [29], [35]. Green synthesis is a safer and more affordable alternative. It relies on plants, microorganisms, or biomolecules. In fact, these biological systems reduce the use of hazardous substances. The nanoparticles produced in this way are compatible with living organisms and are also very stable. More importantly, the method completely excludes the use of heavy toxins. It not only is effective but also does not cause any harm to people or the environment, with no added risks and just cleaner results [27], [33].

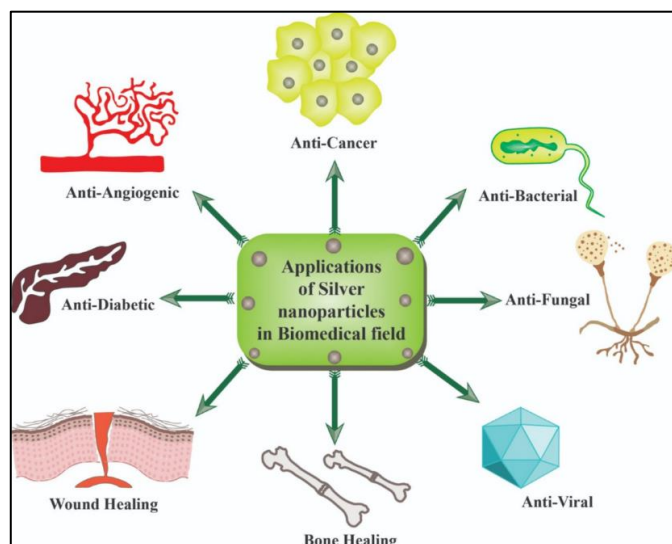


Fig. 2. Applications of AgNPs [source]

Among the different green synthesis methods, the plant-mediated method is considered to be the most beneficial one due to its ease, short time of synthesis, and the ability to scale up. Plant extracts have various phytochemicals like phenolics flavonoids alkaloids terpenoids proteins etc. which are not only able to reduce but also stabilize and cap the nanoparticles during their synthesis [9], [24]. These biomolecules are first of all responsible for the conversion of silver ions (Ag) into silver nanoparticles (Ag) and instantaneously help in achieving enhanced biological functionalities. One of the medicinal plants in India is *Ficus racemosa*, which has been considered for nanoparticle synthesis due to its high level of phytochemicals. Many studies have shown the successful green synthesis of nanoparticles by using *Ficus racemosa* extracts which further confirmed its ability as a reducing and stabilizing agent [11], [31]. Different plant parts such as leaves, stem bark, and latex not only provide bioactive compounds but also play a role in nanoparticle synthesis and further biological property enhancement.

Although significant achievements have been made in the eco-friendly production of silver nanoparticles, a deep knowledge of the synthesis processes, standardization methods, and diverse healthcare-related uses is highly desirable. For this reason, the

current overview aims to provide an in-depth analysis of the synthesis of AgNPs via plants, with *Ficus racemosa* as the main example, along with their characterization and biomedical applications. Besides that, the study outlines the current issues and future possibilities in this rapidly evolving sector [11].

LITERATURE REVIEW

2.1 Review

In the past few years, nanoparticles have become a very popular topic because of the fact that they possess the unique physicochemical properties and are very versatile (they can be used in all sorts of medical environmental industrial, and other areas). For instance, the focus of research into nanomaterials has mostly been on metal-based nanoparticles, especially silver nanoparticles (AgNPs), which offer a wide range of biological and functional properties [3]. The growing need for environmentally friendly and sustainable methods for production motivated the development of green synthesis methods that rely on biological systems to produce nanoparticles [12], [13]. Physical and chemical methods to produce silver nanoparticles have been reported in many studies, but these techniques use toxic substances and consume a lot of energy, so their use is quite limited [29], [35]. On the other hand, green synthesis is really becoming widely accepted, thanks to its environmentally friendly features, low cost, and ease of use. Apart from that, publishing biology-related research depends on plant extracts, microorganisms, and biomolecules very much which may work to reduce metal ions and also help in the attachment of nanoparticles to the surface [33], [27].

Plant-mediated mix of nanoparticles has been studied a lot because plant extracts contain phytochemicals that can reduce and cap nanoparticles Khan et al. Used *Salvia sclarea* leaf extract to make silver nanoparticles and found it worked well against bacteria - probably one of the most effective methods so far [9]. Shaikh et al. synthesized silver nanoparticles using *Acacia concinna* and

demonstrated the role of bioactive compounds in the synthesis and stabilization of the particles [24]. In a broad sense, these papers indicate that plants not only assist in the production of nanoparticles but enhance their biological properties as well. However, it should be noted that this is not only restricted to silver only. Other metals and metal oxides have also been produced by this method. For example, Ali et al. and priya et al. synthesized copper oxide nanoparticles using plant extracts and observed the potent antimicrobial activities of those nanomaterials [16], [17]. Uday et al. even isolated gold nanoparticles from *Abrus precatorius* and demonstrated the antibacterial and anti-inflammatory effects of those nanostructured materials [19], [23]. The method generally succeeds with different materials - which suggests that it could be a great way to produce various nanoparticles that exhibit improved biological performance anyone has ever dreamed of [38]. The technique is well substantiated through several instances. It is not only about achieving small sized particles but also the phytochemicals from the plant have a great impact in deciding the characteristics and performance of the particles in practical uses. This technique is an easy route to produce different types of nanostructures without need for sophisticated instruments or harmful chemicals.

Silver nanoparticles have been the subject of numerous biomedical investigations. These nanoparticles sterilize pathogens by wiping out the structure of their cell walls, generating reactive oxygen species, as well as disrupting cellular functions [5], [20], [26]. Moreover, they serve as vehicles for targeting cancer drugs to the tumor site and act as biosensors for identifying changes in the biological environment. Further, they accelerate the process of wound healing. But these tiny particles do more than one thing - that's what makes them useful in labs today. Scientists are now turning to plants like *Ficus racemosa* to make nanoparticles naturally. The plant has chemicals that reduce metal ions and keep the particles from clumping together. Researchers made

silver nanoparticles using *Ficus racemosa* extracts and found they fight germs well [11], [22], [31]. Using leaves, bark, or latex gives different results and improves the process [32], [36], [37].

Although major advances have been made in eco-friendly nanoparticle production, numerous problems still exist such as differences in production parameters, non-standardization, and limitations in upscaling. So, more studies are needed to improve

production methods and discover other plant-derived sources for effective nanoparticle manufacturing. Here, the paper intends to connect these loopholes through presenting an all-in-one review of environmentally-friendly silver nanoparticle synthesis covering *Ficus racemosa* and its health-related use cases as a main emphasis [39], [40].

Table 1. Summary of Recent Studies on Green Synthesized Nanoparticles

Sr. No.	Author (Year)	Plant / Material Used	Nanoparticle Type	Key Findings / Application
1	Khan et al. (2024) [9]	<i>Salvia sclarea</i> leaves	AgNPs	Effective antibacterial activity; eco-friendly synthesis
2	Shaikh et al. (2022) [24]	<i>Acacia concinna</i>	AgNPs	Bioactive compounds aid reduction and stabilization
3	Aldabaan et al. (2024) [5]	<i>Syzygium aromaticum</i>	AgNPs	Antimicrobial, anticancer, antioxidant activities
4	Asif et al. (2022) [27]	Plant extract (various)	AgNPs	Strong antibacterial potential via green synthesis
5	Ali et al. (2023) [16]	<i>Aegle marmelos</i>	CuO NPs	Significant antimicrobial activity
6	Priya et al. (2023) [17]	<i>Morinda citrifolia</i>	CuO NPs	Enhanced antibacterial efficiency
7	Uday et al. (2022) [19]	<i>Abrus precatorius</i>	AuNPs	Anti-inflammatory and antibacterial properties
8	Varshney et al. (2023) [11]	<i>Ficus racemosa</i>	MgO NPs	Strong antibacterial activity
9	Kumar et al. (2021) [31]	<i>Ficus racemosa</i>	AgNPs	Efficient green synthesis using leaf extract
10	Taha (2022) [25]	Plant extracts	AgNPs/AuNPs	Therapeutic applications in cancer treatment
11	Nigam & Pawar (2022) [18]	ZnO nanoparticles	ZnO NPs	Drug delivery and antimicrobial activity
12	Shreyash et al. (2021) [33]	Review (various plants)	Metal NPs	Wide biomedical applications of green NPs

METHODOLOGY OF REVIEW

3.1 Methodology of Review

This review has been based on the systematic gathering and analyzing the new literature on the green synthesis of silver nanoparticles and their

biomedical applications. A rigorous search strategy was used to collect the related articles from reputed scientific databases such as Google Scholar, ScienceDirect, SpringerLink, and PubMed.

3.2 Search Strategy

The literature search was done using keywords such as “silver nanoparticles,” “green synthesis,” “plant-mediated synthesis,” “Ficus racemosa,” “biomedical applications,” and “nanoparticle characterization.”

Boolean operators AND/OR were used to combine search terms and thus collect more relevant publications for the review. The search was mainly limited to articles published from 2020 to 2024 so as to include the most recent developments in the area.

3.3 Inclusion and Exclusion Criteria

Table 2. Inclusion and Exclusion criteria

Criteria Type	Inclusion Criteria	Exclusion Criteria
Study Focus	Studies on green synthesis of silver nanoparticles using plant extracts	Studies focusing only on chemical or physical synthesis methods
Nanoparticle Type	Silver nanoparticles (AgNPs) and related green-synthesized nanoparticles	Studies not related to nanoparticles or unrelated materials
Methodology	Articles including synthesis, characterization (UV–Vis, FTIR, SEM, EDS, XRD, TEM), and applications	Studies lacking experimental details or proper methodology
Applications	Biomedical applications such as antimicrobial, anticancer, antioxidant, biosensing	Studies not addressing biological or biomedical applications
Publication Type	Peer-reviewed journal articles and review papers	Conference abstracts, reports, unpublished or non-peer-reviewed data
Language	Articles published in English	Non-English publications
Time Frame	Studies published between 2020–2024	Studies published before 2020 (unless highly relevant)

3.4 Data Extraction and Analysis

The relevant information from the selected papers was thoroughly extracted, analyzed, and then classified based on synthesis methods, plant sources, characterization techniques, and their applications. To find the trends and advantages as well as the

drawbacks of green synthesis methods, a comparative analysis was done. Special attention was given to the research on Ficus racemosa and other medicinal plants because of their phytochemical richness and the potential they hold in synthesizing nanoparticles [11], [31].

Table 3 Data Extraction and analysis framework

Step No.	Process Stage	Description	Key Parameters / Variables	Purpose
1	Article Selection	Relevant studies were selected based on predefined inclusion and exclusion criteria	Year (2020–2024), relevance to green synthesis, peer-reviewed status	To ensure quality and relevance of selected literature
2	Data Extraction	Important information from each study was systematically collected and recorded	Author, year, plant name, plant part, nanoparticle type, synthesis conditions	To create a uniform dataset for comparison

Step No.	Process Stage	Description	Key Parameters / Variables	Purpose
3	Synthesis Parameters Collection	Experimental conditions were extracted from each paper	pH, temperature, reaction time, concentration of AgNO ₃ , extract ratio	To analyze factors affecting nanoparticle formation
4	Characterization Data Collection	Techniques used to confirm nanoparticle formation were recorded	UV-Vis peak ($\approx 400\text{--}450\text{ nm}$), FTIR functional groups, FESEM morphology, EDS composition	To compare validation methods across studies
5	Categorization of Studies	Studies were grouped based on different criteria	Plant source, nanoparticle type (AgNPs, CuO, AuNPs), application type	To organize literature systematically
6	Comparative Analysis	Cross-comparison of studies was performed	Particle size (10–100 nm), shape (spherical, oval), efficiency of synthesis	To identify trends and differences
7	Application Analysis	Biological and functional applications were evaluated	Antimicrobial, anticancer, antioxidant, biosensing properties	To determine practical significance of nanoparticles
8	Critical Evaluation	Strengths and limitations of each study were analyzed	Eco-friendliness, cost, reproducibility, scalability issues	To assess reliability and challenges
9	Focused Analysis (<i>Ficus racemosa</i>)	Special attention was given to studies using <i>Ficus racemosa</i>	Plant parts (leaves, bark), phytochemicals, nanoparticle efficiency	To highlight unique contribution of the study [11], [31]
10	Synthesis of Findings	Final conclusions were drawn by integrating all analyzed data	Trends, research gaps, future scope	To provide a comprehensive understanding of the topic

3.5 Scope and Limitations

Since we are limited by what the databases can provide and the selection of studies to be included in the review, not every relevant paper has been covered by the review - there are some gaps. In fact, working conditions change from one experiment to another, and there is a lack of consistency in the reporting - hence making a comparison between results is a real challenge. Besides, the ones we have analyzed depict a fairly accurate picture of the present scenario in the green synthesis of silver nanoparticles.

GREEN SYNTHESIS OF SILVER NANOPARTICLES (AgNPs)

Green fusion of silver nanoparticles (AgNPs) offers a safer, more sustainable path than traditional methods. Plant extracts reduce silver ions (Ag) to metallic silver (Ag) without relying on harsh chemicals or high energy. The process avoids toxic reagents and heavy energy use. This method is simple, effective, and widely applicable. It relies entirely on natural biological systems for nanoparticle formation [10], [29], [35].

• Role of Plant Metabolites

Plant extracts contain a vast range of bioactive compounds such as phenolics, flavonoids, alkaloids, terpenoids, proteins, and reducing sugars. These phytochemicals play dual role in nanoparticle synthesis:

1. Reducing Agents:

They donate electrons to silver ions (Ag^+), converting them into neutral silver atoms (Ag^0).

2. Stabilizing/Capping Agents:

They bind to the surface of nanoparticles, preventing aggregation and enhancing stability.

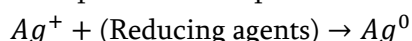
Studies have shown that the efficiency of nanoparticle synthesis is related to the concentration and composition of these phytochemicals [9], [24]. The presence of functional groups such as hydroxyl ($-\text{OH}$), carbonyl ($\text{C}=\text{O}$), and amine ($-\text{NH}_2$) groups plays a very important role in reduction and stabilization process.

• Mechanism of Green Synthesis

The green synthesis of AgNPs generally involves three main stages:

1. Activation Phase (Reduction)

In this stage, silver ions (Ag^+) present in silver nitrate (AgNO_3) solution are reduced to silver atoms (Ag^0) by phytochemicals present in the plant extract:



This reduction process is often shown by a visible color change of the solution from colorless to brown due to surface plasmon resonance (SPR).

2. Growth Phase (Nucleation and Aggregation)

The reduced silver atoms collection to form small clusters (nuclei), which further grow into nanoparticles. The size and shape of nanoparticles depend on reaction parameters such as pH, temperature, concentration, and time.

3. Termination Phase (Stabilization)

During this phase, phytochemicals cap the nanoparticles, stabilizing them and preventing further aggregation. This results in the formation of stable, well-dispersed silver nanoparticles.

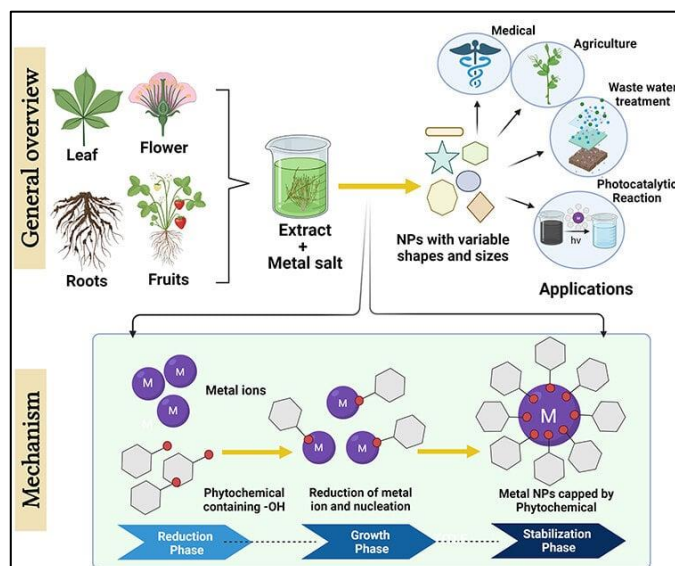


Fig 3 Mechanism of Green Synthesis of Silver Nanoparticles [source]

• General Procedure of Green Synthesis

The typical procedure for plant-mediated synthesis of AgNPs :

1. Preparation of plant extract (leaves, bark, latex, etc.)
2. Filtration to remove the impurities
3. Mixing the extract with silver nitrate (AgNO_3) solution
4. Incubation under controlled conditions (temperature, time, pH)
5. Observation of color change indicating nanoparticle formation
6. Purification and characterization of nanoparticles

This method is simple, cost-effective and suitable for large-scale production [27], [33]

• Factors Affecting Synthesis

Several parameters influence the synthesis of AgNPs:

1. **pH:** Affects reduction rate and particle size
2. **Temperature:** Higher temperatures increase reaction rate
3. **Concentration of AgNO_3 :** Determines yield and size
4. **Reaction Time:** Influences nanoparticle growth and stability

Optimization of these factors is essential for controlled synthesis of nanoparticles with desired properties [30].

- **Advantages of Green Synthesis**

1. Is Eco-friendly and non-toxic
2. Cost-effective and energy-efficient
3. Biocompatible nanoparticles
4. No need for hazardous chemicals
5. Suitable for biomedical applications

Ficus racemosa has been a popular subject of research in the field of green synthesis, mainly because of the high phytochemical content of the plant. The leaf, bark, and latex extracts of the plant are a source of the bioactive compounds that can reduce silver ions efficiently and help in the stabilization of nanoparticles. Research has shown that it is possible to synthesize nanoparticles using *Ficus racemosa*, and these nanoparticles exhibit notable antibacterial properties along with a well regulated particle size. [11], [31]

CHARACTERIZATION AND APPLICATIONS OF SILVER NANOPARTICLES

5.1 Characterization Techniques of AgNPs

Table 4. Characterization Techniques of Silver Nanoparticles

Sr. No.	Technique	Principle	Key Observations	Significance
1	UV-Visible Spectroscopy	Based on surface plasmon resonance (SPR) of electrons in nanoparticles	Absorption peak around 400–450 nm (commonly ~430 nm)	Confirms formation and stability of AgNPs
2	FTIR (Fourier Transform Infrared Spectroscopy)	Identifies functional groups based on infrared absorption	Presence of –OH, C=O, –NH ₂ groups	Indicates role of phytochemicals in reduction and capping
3	FESEM (Field Emission Scanning Electron Microscopy)	Uses electron beam to visualize surface morphology	Nanoparticles appear spherical/oval; size ~10–100 nm	Determines size, shape, and surface structure
4	EDS (Energy Dispersive X-ray Spectroscopy)	Detects elemental composition via X-ray emission	Strong silver (Ag) peak; presence of C, O	Confirms elemental composition and purity
5	XRD (X-ray Diffraction)	Determines crystalline structure	Peaks corresponding to silver crystal planes	Confirms crystalline nature of AgNPs

5.1.1 UV-Visible Spectroscopy

One of the leading methods to validate the synthesis of silver nanoparticles is UV-Visible spectroscopy. AgNPs preparation is signaled by the development of a distinctive surface plasmon resonance (SPR) peak, which is usually between the wavelengths of 400 and 450 nm. The collective oscillations of the nanoparticles' surface electrons are responsible for this peak. On the other hand, few studies have

demonstrated their synthesized AgNPs by recording absorption spectra at around 430 nm, which is also the signature of their stability in solution [8], [14].

5.1.2 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis helps to characterize the chemical groups that are responsible for the reduction and stabilization of nanoparticles in plant extracts. Functional groups including hydroxyl (–OH),

carbonyl (C=O), and amine (-NH) groups are the main contributors in the synthesis of AgNPs. The detection of these groups supports the phytochemicals' role in capping and stabilizing the silver nanoparticles (AgNPs) [24].

5.1.3 Field Emission Scanning Electron Microscopy (FESEM)

FESEM provides information on a nanoparticle's shape, size, and surface features. AgNPs obtained through the green synthesis method are mostly spherical or oval in shape. Their size range is generally between 10 and 100 nm. Actually, their appearance is quite important. Surface characteristics determine their cell-binding ability. That, in turn, influences their effectiveness in practical applications [25].

5.1.4 Energy Dispersive X-ray Spectroscopy (EDS)

EDS characterization was used to confirm the elemental composition of nanoparticles. A strong peak corresponding to silver (Ag) confirms the production of silver nanoparticles. On the other hand, the presence of elements such as oxygen and carbon indicates that the phytochemicals from the plants acted as stabilizers of nanoparticles [24].

5.2 Biomedical Applications of AgNP

The unique physicochemical properties of silver nanoparticles, including their large surface area and increased reactivity, render them very potent for different biomedical uses.

5.2.1 Antimicrobial Activity

Silver nanoparticles have great antibacterial and antifungal properties. They break down the bacterial and fungal membranes, generate reactive oxygen species, and interfere with the functioning of DNA and proteins. However, this eventually leads to cell death. Studies show green-blended AgNPs work well against microbes. The results are consistent across different strains. The mechanism involves multiple pathways [5], [27], [34].

5.2.2 Antifungal and Antiviral Activity

In addition to antibacterial effects, AuNPs display potent antifungal and antiviral activities as well. They

kill fungi by breaking up their cell walls and membranes. In the case of viruses, they inhibit viral replication and prevent the virus from attaching to host cells. Thus, these features make them suitable for use in managing both plant and human pathogens. [5].

5.2.3 Anticancer Activity

The silver nanoparticles can dramatically reduce cancer by making cancer cells produce harmful oxygen and even kill themselves through programmed cell death, a way cancer cells can be deprived of their life. Moreover, as they are very tiny, they can easily get in the cancer cells and hence, they are very efficient elements in targeted therapy and in drug delivery systems. [25], [28].

5.2.4 Antioxidant and Anti-inflammatory Activity

AgNPs produced with the help of plant extracts show antioxidant activity because phytochemicals stay on their surface. Thus, they are able to capture free radicals and have anti-inflammatory effects, which may be useful in the treatment of different disorders[4], [5], [26].

5.2.5 Biosensing and Bioimaging Applications

Given their optical and electronic features, silver nanoparticles are one of the most popular types of nanoscale materials for biosensors and bioimaging. They not only improve the detection of signals but also enable the visualization of biological systems, thereby helping in the development of diagnostic and therapeutic tools [6], [15], [33].

5.3 Metallic and Metal Oxide Nanostructures with Desired Characteristics

Metallic and metal oxide nanostructures have attracted significant attention due to their tunable physicochemical properties and wide range of applications in biomedical, environmental, and industrial fields. Metallic nanoparticles such as silver (Ag), gold (Au), and copper (Cu), as well as metal oxide nanoparticles like zinc oxide (ZnO), titanium dioxide (TiO₂), and copper oxide (CuO), exhibit unique optical, electrical, catalytic, and antimicrobial properties.

The functionality of these nanostructures is strongly dependent on their size, shape, surface area, and crystallinity. For instance, nanoparticles in the range of 10–100 nm demonstrate enhanced surface reactivity and biological interactions. Spherical nanoparticles provide uniform interaction, while rod-shaped or triangular structures exhibit improved catalytic and optical properties due to anisotropic behavior.

Desired characteristics of nanostructures include:

- Controlled particle size and uniform distribution
- High surface-to-volume ratio
- Stability and resistance to aggregation
- Biocompatibility for biomedical applications
- Enhanced reactivity and targeted functionality

Metal oxide nanoparticles, in particular, offer advantages such as **thermal stability, photocatalytic activity, and chemical resistance**, making them suitable for drug delivery, environmental remediation, and sensor applications.

The ability to tailor these characteristics through synthesis methods plays a crucial role in determining their practical applications.

5.4 Advantages of Biogenic Synthesis and Correlation with Previous Studies

Biogenic or green synthesis of nanoparticles offers several advantages over conventional physical and chemical methods. It utilizes plant extracts, microorganisms, or biomolecules as reducing and stabilizing agents, thereby eliminating the need for toxic chemicals and high energy input.

Key advantages include:

- Eco-friendly and sustainable approach
- Cost-effective and simple process
- Biocompatibility and reduced toxicity

- Simultaneous reduction and stabilization by phytochemicals
- Scalability for large-scale production

Several studies support these advantages. For example, Khan et al. [9] demonstrated efficient antibacterial activity of green-synthesized AgNPs using *Salvia sclarea*. Similarly, Shaikh et al. [24] reported that phytochemicals present in *Acacia concinna* significantly enhance nanoparticle stability and functionality. Asif et al. [27] highlighted that green synthesis produces nanoparticles with superior antimicrobial efficiency compared to chemically synthesized counterparts.

These findings collectively confirm that biogenic synthesis not only reduces environmental impact but also improves the biological performance of nanoparticles, making it highly suitable for biomedical applications.

5.5 Comparative Study of Nanoparticle Synthesis Routes

The selection of a suitable synthesis route plays a crucial role in determining the size, morphology, stability, cost, and application potential of the resulting nanoparticles. Conventional methods such as chemical reduction and physical techniques provide better control over particle size and yield but often involve toxic chemicals, high energy consumption, and expensive equipment. Advanced techniques like sol-gel, hydrothermal, microwave irradiation, and electrospinning enable the production of nanostructures with tailored properties for specific applications. Therefore, a comparative understanding of these synthesis routes is essential to optimize nanoparticle production based on desired characteristics and end-use applications.

Table 5. Comparative Summary of Nanoparticle Synthesis Routes

Method	Principle	Reaction Time	Cost	Advantages	Limitations
Chemical Reduction	Use of reducing agents (NaBH ₄ , citrate)	Fast (minutes–hours)	Moderate	High yield, controlled size	Toxic chemicals, environmental risk
Physical Methods	Evaporation, laser ablation	Slow–moderate	High	Pure nanoparticles	High energy consumption
Green Synthesis	Plant/microbial extracts reduce metal ions	Moderate	Low	Eco-friendly, biocompatible	Less control over size
Sol-Gel Method	Formation of colloidal solution (sol → gel)	Moderate	Moderate	Uniform particles, good control	Complex process
Hydrothermal	High temperature & pressure in aqueous solution	Slow	Moderate	High crystallinity	Requires special equipment
Microwave Irradiation	Rapid heating using microwave energy	Very fast	Moderate	Uniform heating, quick synthesis	Limited scalability
Electrospinning	Fiber-based nanoparticle synthesis	Moderate	High	Nanofiber structures	Complex setup

ROLE OF *FICUS RASEMOSA* IN GREEN SYNTHESIS OF AgNP

Ficus racemosa, known as the cluster fig tree, grows across India and is deeply embedded in traditional healing practices. Its phytochemicals - phenolics, flavonoids, alkaloids, tannins - are known to stabilize metal ions during nanoparticle formation. Researchers use it for green combination because it is solidly rich in these compounds. The process relies on the plant's natural ability to reduce metals into nanoparticles. A full analysis shows this method avoids toxic chemicals. Scientists have found it effective in producing stable nanostructures without harsh reagents. [11], [31]



Fig.3. Tree of *Ficus racemosa* [Source]

6.1 Plant Parts Used for Synthesis

Various parts of *Ficus racemosa* have been used for nanoparticle synthesis, including:

- **Leaves**
- **Stem bark**
- **Latex**

Different phytochemical kinds and amounts found in these plant sections affect the size, stability, and

production of nanoparticles. Research has demonstrated that the high concentration of reducing agents in leaf extracts makes them very efficient [31].

6.2 Synthesis Process and Observations

The synthesis of silver nanoparticles was achieved by combining plant extracts with the silver nitrate (AgNO_3) solution in a controlled environment. The reduction of silver ions (Ag^+) to metallic silver (Ag^0) is marked by a visible color change from colorless to brown due to surface plasmon resonance (SPR), which serves as a confirmation of the nanoparticle formation [29], [33].

Analyzing by UVVisible spectroscopy usually displays a distinctive absorption peak at about 400-450 nm, mostly near 430 nm, which is a clear indication that the silver nanoparticles (AgNPs) have been formed and are stable. This result is in agreement with the other scientific papers related to the green made silver nanoparticles [9].

6.3 Morphology and Size Analysis

Field Emission Scanning Electron Microscopy (FESEM) analysis shows that green synthesized AgNPs are generally:

- Spherical or oval in shape
- Uniformly distributed

The size of nanoparticles is found between 10–100 nm, depending on synthesis conditions and plant extract composition [3], [29]. Variations in size is observed from different plant parts of *Ficus racemosa* are attributed to differences in phytochemical composition.

6.4 Elemental Composition

Energy Dispersive X-ray Spectroscopy (EDS) analysis shows silver is the dominant element in the nanoparticles. Carbon and oxygen are also present, which points to plant-based molecules acting as capping agents. These biomolecules help stabilize the particles during mix. The data confirms the role of natural compounds in forming the nanostructure [24].

6.5 Significance of *Ficus racemosa* in Nanoparticle Synthesis

The use of *Ficus racemosa* offers several advantages:

- Works as natural reducing and stabilizing agent
- Allows eco-friendly and sustainable synthesis
- It Produces biocompatible nanoparticles
- Eliminates the need for toxic chemicals

Previous studies have demonstrated that nanoparticles synthesized using *Ficus racemosa* show significant antibacterial activity and potential biomedical applications [11], [31].

6.6 Key Findings

1. Successful green mix of AgNPs using different plant parts.
2. Characteristic SPR peak (~430 nm) confirms nanoparticle formation.
3. Nanoparticles display spherical morphology with nanoscale size.
4. Presence of bioactive compounds boosts stability and functionality.
5. Strong potential for biomedical and antimicrobial applications.

CHALLENGES LIMITATION AND FUTURE SCOPE

7.1 Challenges in Green Synthesis of Silver Nanoparticles

Green synthesis has its merits, but the scope of its use is still quite limited by various challenges. First of all, one major challenge in using green synthesis is controlling the size, shape, and uniformity of nanoparticles. This is because the manufacture of nanoparticles can be affected by the differences in the phytochemical composition of plant extracts. As plant metabolites not only differ among species but also geographical locations and extraction methods, it is indeed challenging to achieve consistent results. [35], [33].

Another major point that needs emphasis is the fine-tuning of the synthesis parameters such as pH, temperature, reaction time, and precursor concentration. Even minor deviations in these parameters can have a significant impact on the creation and stability of nanoparticles. Apart from this, figuring out the precise process of reduction and stabilization at the molecular level remains a

challenging problem and requires further investigation. [27].

7.2 Limitations

7.2.1 Lack of Standardization

The absence of well-defined standards in the use of green synthesis technologies is a major reason why it is very difficult to replicate a study based on its findings. Moreover, the comparison between different studies is hindered by the variations in the experimental arrangements and reporting methods. [29] .

7.2.2 Scalability Issues

Even though green synthesis is cost-effective at the laboratory level, the difficulties of ensuring nanoparticle quality and homogeneous reaction conditions make large-scale production challenging.

7.2.3 Limited Toxicity and Clinical Studies

Even though AgNPs have shown potential for biomedical applications, their long-term toxicity, biocompatibility, and clinical safety are still largely unknown. More investigation is necessary to fully understand the interaction of nanoparticles with biological systems before their extensive medical application [26] .

7.2.4 Stability and Storage

Without suitable storage conditions or stabilizer chemicals, nanoparticles produced through green methods can have issues with aggregation and may lose stability over time.

7.3 Future Scope

Green synthesis of silver nanoparticles is an area that provides lots of opportunities for new research and development [1].

Table 6. Future Scope

Sr. No.	Area	Future Scope
1	Synthesis	Development of standardized and scalable green synthesis methods
2	Mechanism Study	Better understanding of molecular mechanisms of nanoparticle formation
3	Biomedical Applications	Clinical studies for drug delivery, cancer therapy, and wound healing
4	Agriculture	Use in plant disease control and crop protection
5	Environmental Applications	Water purification and pollutant removal
6	Advanced Technologies	Integration with AI, biosensors, and nanomedicine
7	Plant Research	Exploration of more medicinal plants like <i>Ficus racemosa</i>

CONCLUSION

Silver nanoparticles (AgNPs) have attracted great attention in nanotechnology due to their unique physical and chemical properties. It appears that green synthesis is the best option as it is safe, cheap, and environmentally friendly. Among various plant-based methods, biogenic synthesis using plant extracts is superior because it relies on natural compounds to reduce and stabilize the particles without using any harmful chemicals. This makes them more biocompatible. UV, Visible spectroscopy FTIR FESEM,

and EDS are major techniques for confirming the synthesis of nanoparticles and characterizing their morphology and structure. AgNPs exert antimicrobial anticancer antioxidant, and anti-inflammatory effects. These biological activities offer possibilities for applications in nanoscale medicine, agriculture, and environmental remediation. However, a major drawback is the lack of uniform performance shown by different studies. The highest level of proof is experimental evidence where AgNPs have shown

better efficacy compared to conventional methods in various cases.

One of the reasons why special focus on *Ficus racemosa* is merited is that this species is a very good candidate to be a natural resource for nanoparticle synthesis due to its abundant phytochemical content as well as its production of stable nanoparticles having the properties desirable by the market. Nevertheless, some problems like the absence of standardization, problems in the production on a large scale, and the scarcity of clinical validation have to be solved. To sum up, green synthesized silver nanoparticles open up a new research frontier with a lot of untapped potential for new discoveries and innovations in the future. Besides routine experiments on optimizing these nanoparticles and making them available on a large scale, applications of these nanoparticles in clinics will make them more useful and will lead to their acceptance in the market..

AUTHOR CONTRIBUTION

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