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Green Synthesis Of Silver Nanoparticles Using Moringa Oleifera Leaf Powder: A Review On Characterization And Antimicrobial Applications

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ABSTRACT:
Green nanotechnology is a more sustainable, environmentally friendly, and less expensive alternative to the traditional physical and chemical methods for the synthesis of nanoparticles(Rajeshkumar & Bharath, 2017). The current paper is a literature survey that looks into the biogenic production of silver nanoparticles (AgNPs) with Moringa oleifera leaf powder, highlighting the material's potential as a reducing as well as a stabilizing agent("(PDF) Green Synthesis of Silver Nanoparticles from Moringa Oleifera Leaf Extracts and Its Antimicrobial Potential," 2025). The silver nanoparticles show to be very versatile due to their antimicrobial, antioxidant, and catalytic properties, which lead to their usage in different fields such as medicine, agriculture, and environmental management((PDF) Evaluation of Antibacterial Efficacy of Green Synthesized Silver Nanoparticles from Moringa Oliefera Aqueous Root Extract, n.d.). The present work is the first one to detail the mechanism of green synthesis, the phytochemical profile of Moringa extract and its effect on nanoparticle structure. Characterization of samples through UV-Vis spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM) have been thoroughly discussed here. The antimicrobial potency of the metal-loaded Moringa composite has also been identified with the help of bacterial strain(Yedoti et al., 2024)s. The review article focus about benefits, applications, and future potentials of Moringa-based nanoparticle synthesis. Here, green synthesis not only restricts the consumption of toxic chemicals to a great extent but also promotes the sustainability development principles by employing plant-derived biomolecules as natural capping and reducing agents. Bioactive compounds in Moringa oleifera such as flavonoids, phenolics, alkaloids, and terpenoids are responsible for forming nanoparticles, enhancing the stability and functionality of synthesized AgNPs. The process offers an easy, fast, and environmentally friendly pathway that can be scaled up conveniently without the requirement of high pressure or heat, which is economically viable for industrial-scale applications. In addition, this research investigates the impact of different synthesis parameters like pH, temperature, concentration of silver nitrate, and reaction time on nanoparticle size, morphology, and dispersity. The UV–Vis spectra indicative of characteristic surface plasmon resonance at 420–450 nm verify successful formation of AgNP, and XRD results ensure the crystalline nature. SEM and TEM images also gain a better understanding of particle morphology, displaying evenly distributed spherical nanoparticles. The antimicrobial assays exhibit strong inhibitory activity of Moringa-derived silver nanoparticles against Gram-positive and Gram-negative bacterial strains, indicating possible applications in the development of natural antimicrobial drugs. Their catalytic and antioxidant activity provide further prospects for use in environmental detoxification, wastewater treatment, and in improving agriculture. In sum, this review offers a comprehensive knowledge on Moringa-mediated green synthesis of AgNPs, with a focus on its advantages over traditional methods and on its promising uses in various scientific and industrial fields. The article ends with an outlook for the future, and it posits that the synergy between plant-based nanotechnology can give rise to the next generation of biocompatible and sustainable NP(Yedoti et al., 2024).
***Keywords**: Moringa oleifera, silver nanoparticles, green synthesis, antimicrobial activity, nanobiotechnology*

1. INTRODUCTION:

Nanotechnology has revolutionated scientific modernies by furnishing materials that have the same unique physicochemical properties but are different from those of their bulk counterparts. Ag silver nanoparticles (AgNPs) are considered one of the largest groups of nanomaterials, their main characteristics being the optical, catalytic, and antimicrobial features. Nevertheless, the traditional synthesis methods usually require the use of toxic chemicals such as sodium borohydride, hydrazine, and citrate, all of which are both environmental and biological hazards (Sharma et al., 2023). In order to get rid of those drawbacks, the green synthesis which involves plant-based reducing agents has become a method that is not only sustainable but also non-toxic.

Moringa oleifera (family: Moringaceae) is the plant that grows in tropical and subtropical regions and can be found almost everywhere. The leaves of the tree have been reported to contain high levels of polyphenols, vitamins, and proteins that should be natural reducing and stabilizing agents. These biomolecules encourage the conversion process of Ag^+ ions into metallic Ag^0 nanoparticles and keep them from agglomerating via their capping mechanisms. New research shows that Moringa-based AgNPs have excellent antimicrobial, antioxidant, and catalytic properties (Palanisamy et al., 2021; Yedoti et al., 2024). This paper is a first step towards integrating the data which report Moringa oleifera- assisted silver nanoparticle synthesis, emphasizing on the mechanisms, techniques of characterization and applications.

1.1 Principle of Green Synthesis

Producing silver nanoparticles (AgNPs) through green synthesis is a process of bio-reduction, a capping, and stabilization of nanoparticles via phytochemicals found in moringa extracts. The overall reaction is when silver nitrate ($AgNO_3$) is converted to metallic silver (Ag^0) with the help of antioxidants and reducing biomolecules. Reduction in the mentioned compounds is facilitated by flavonoids, terpenoids, alkaloids, and phenolic acids that play a significant role in electron donation (Bhandari & Dhasmana, 2023). Nanoparticles become stable because of proteins and polysaccharides in the extract which do not allow agglomeration.

The typical parameters influencing synthesis include:

1. Concentration of $AgNO_3$ solution: A concentration of 1 mM is usually the most suitable option for reduction.
2. Extract-to-metal ratio: A ratio of 1:9 (v/v) is the most common use.
3. pH and temperature: Elevating the pH and moderate heating (50–70°C) are the two ways for a better reduction process.
4. Reaction time: Nanoparticles are indicated by color change from pale yellow to brownish-red within 4–6 hours.

The reaction can be illustrated as follows:

Ag^+ + phytochemical → Ag^0 (nanoparticles) + oxidized by- products.

Figure 1: Moringa oleifera

2. REVIEW OF LITERATURE:

2.1 Preparation of Moringa oleifera Leaf Extract

Leaves of Moringa are washed, dried in the shade, and powdered in a dry mill to a fine consistency. 5 grams of powder is mixed with 100 mL of distilled water and then the mixture is heated at 60°C for 30 minutes. The extract is filtered (Whatman No. 1) and allowed to cool to room temperature. Phytochemical screening reports the presence of tannins, phenols, flavonoids, and saponins, which are the major contributors to the nanoparticle formation process (Saikanth et al., 2023). The extract must be new every time to keep the reducing potential intact.

Figure 2: Procedure of leaf extract (Saikanth et al., 2023)

1.1 Synthesis of Silver Nanoparticles

The normal synthesis procedure involves the addition of 10 mL of Moringa extract dropwise to 90 mL of 1 mM $AgNO_3$ solution with constant stirring. A reddish-brown color change from pale yellow is the visual confirmation of AgNP formation, along with the possible explanation of SPR. More prolonged stirring (4–6 hours) and moderate heating can be used as a strategy to get a total reduction. A centrifugation of the obtained colloid can be done at 10,000 rpm for 15 minutes to isolate the nanoparticles. The pellet thus obtained is re-suspended in distilled water and ethanol for washing and then dried for further characterization (Mohapatra et al., 2024).

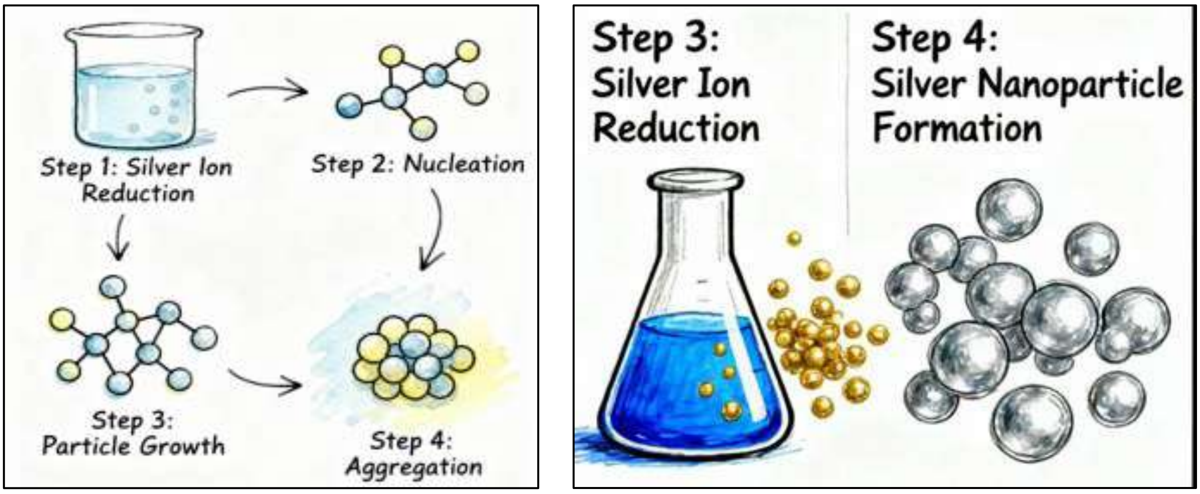

Figure 3: The schematic representation of AgNPs synthesis assisted by Moringa oleifera (Mohapatra et al., 2024)

Table 1. Typical synthesis parameters for Moringa oleifera- mediated AgNPs

PARAMETER	TYPICAL CONDITION	REFERENCE
$AgNO_3$ concentration	1 mM	Sharma et al., 2023
Extract ratio	1:9 (v/v)	Palanisamy et al., 2021
Temperature	60–70°C	Yedoti et al., 2024
Reaction time	4–6 hours	Mohapatra et al., 2024
pH	7–9	Bhandari & Dhasmana, 2023

1.2 Characterization Techniques

- UV–Vis Spectroscopy: The surface plasmon resonance peak between 420–470 nm is indicative of silver nanoparticle (AgNP) formation. The absorption maxima around 450 nm for AgNPs synthesized using Moringa have been reported, implying the generation of spherical nanoparticles of the uniform size (Palanisamy et al., 2021).

- X-ray Diffraction (XRD): The XRD result proves the crystal structure of the sample. The various diffraction peaks detected at 2θ = 38°, 44°, 64°, and 77°, can be assigned to (111), (200), (220), and (311) planes of fcc silver, respectively. The size of the crystal grain is between 15 and 30 nm (Yedoti et al., 2024).
- Scanning Electron Microscopy (SEM): SEM images show regular, spherical, nanoparticles with very few clusters. The surface topography confirms the distribution of the particles in the range of 50–100 nm.
- Transmission Electron Microscopy (TEM): TEM is commonly used to measure the size and to determine the shape of nanoparticles. The silver nanoparticles obtained from Moringa leaf show clear crystalline lattice fringes and have a narrow size range (10–50 nm).

1.3 Antimicrobial Activity

The antimicrobial potential of silver nanoparticles is first tested by the agar well or disc diffusion method. The antimicrobial profile of Moringa-derived AgNPs is strong and they are active against both Gram-positive and Gram-negative bacterial strains. The inhibition zone of 14–20 mm is obtained at concentrations of 50–100 µg/mL. (Mohapatra et al., 2024). The antimicrobial action is attributed to the rupture of bacterial membranes, blockage of enzymes involved in respiration, and production of reactive oxygen species (ROS).

Table 2. Comparative antimicrobial activity of Moringa- mediated AgNPs

Microorganism	Zone of Inhibition (mm)	Reference
E. coli	18 ± 0.5	Mohapatra et al., 2024
S. aureus	15 ± 0.7	Sharma et al., 2023
P. aeruginosa	14 ± 0.6	Saikanth et al., 2023

2. Advantages of Moringa oleifera-Mediated Synthesis

- Eco-friendly: The process relies on renewable plant resources and therefore no toxic chemicals are used.
- Biocompatible: The natural capping agents not only allow stability but also reduce the cytotoxicity of nanoparticles.
- Cost-effective: The process can be carried out efficiently with minimum equipment and raw materials that are easily available.
- High yield and stability: Part of protein and phenolic content in the extract assure long term colloidal stability of nanoparticles.
- Left to his own devices, Moringa extract creates nanoparticles that are smaller and more stable compared to those produced using neem, aloe vera and tulsi extracts at similar conditions (Bhandari & Dhasmana, 2023).

3. Applications and Future Perspectives

- Biomedical applications: AgNPs made from Moringa extracts give the possibility of wound healing, antimicrobial coatings, and drug delivery as their field of application. Due to their strong bactericidal properties, they are considered an ideal resource for medical textiles and surfaces of implants.
- Agricultural applications: Seed germination, plant growth and pest control can be greatly improved through the use of AgNPs, however, in order to get the desired results, minimal concentration needs to be applied (Saikanth et al., 2023).
- Environmental applications: Apart from other uses, they can be installed in water purification, biosensing and pollutant degradation devices.
- The future vision: The future research focus shall be on industrial production, understanding phytochemical mechanisms through spectroscopic mapping and developing hybrid nanomaterials (Ag–Cu, Ag–ZnO) to increase multifunctionality. Sustainable development would then be further enabled by the adoption of waste valorization frameworks, one example of which would be the use of Moringa-based nanotechnology (Sharma et al., 2023).

4. CONCLUSION

The green synthesis of AgNPs utilizing Moringa oleifera leaf powder is a method that concurs with the concept of sustainability and it is also very effective in producing nanomaterials that have strong antimicrobial properties. Their characterizations can be identified as crystalline, stable and well-dispersed in nature. Appropriate references to the scientific confirmation of AgNPs synthesized from Moringa extracts indicate that they greatly outdo most other plant-based systems in the stability and antimicrobial activity aspects. This conclusion echoes the ideas behind green chemistry and sustainable development and shows that Moringa oleifera could hold the key to a future where less polluting and more sustainable processes are used for nanomaterial syntheses.

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