



GREEN SYNTHESIS OF METAL NANOPARTICLES FROM PLANT EXTRACTS AS NANO-ANTIBIOTICS

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Article Received on 26 Dec. 2025,
Article Revised on 16 Jan. 2026,
Article Published on 01 Feb. 2026,
<https://doi.org/10.5281/zenodo.18425999>

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How to cite this Article: Sonika Pal^{1*}, Dr. Pallavi Sharma². (2026). Green Synthesis of Metal Nanoparticles From Plant Extracts as Nano-Antibiotics. World Journal of Pharmacy and Pharmaceutical Sciences, 15(2), 344-354. This work is licensed under Creative Commons Attribution 4.0 International license.

ABSTRACT

The rapid emergence of multidrug-resistant (MDR) microorganisms has intensified the global demand for alternative antimicrobial strategies. Plant-mediated green synthesis of metal nanoparticles has gained attention as an eco-friendly, cost-effective, and biologically potent approach to combat resistant pathogens. In the present study, leaves of *Monoon longifolium*, *Ricinus communis*, *Ficus benjamina*, and *Sterculia rubiginosa* were used for the synthesis of metal nanoparticles using copper sulphate and magnesium sulphate as precursor salts. Crude plant extracts and their corresponding nanoparticles were evaluated for antibacterial activity against *Staphylococcus aureus* (MTCC 902) and *Pseudomonas aeruginosa* (MTCC 741) using agar well diffusion and minimum inhibitory concentration (MIC) assays.

Phytochemical screening revealed the presence of flavonoids, terpenoids, tannins, saponins, and steroids, particularly in *Monoon longifolium*, which correlated with enhanced antibacterial activity. Metal nanoparticles synthesized using *Monoon longifolium* extract exhibited significantly higher antibacterial efficacy than crude extracts and the standard antibiotic tetracycline. These findings support the potential of plant-based metal nanoparticles as effective nano-antibiotics and promising alternatives to conventional antimicrobial agents.

KEYWORDS: Green synthesis, Metal nanoparticles, Nano-antibiotic, Medicinal plants, Antibacterial activity.

1. INTRODUCTION

Infectious diseases remain one of the leading causes of morbidity and mortality worldwide, despite remarkable advances in modern medicine and biotechnology.^[1] The discovery of antibiotics in the early twentieth century revolutionized healthcare and significantly reduced deaths caused by bacterial infections. However, the extensive and often indiscriminate use of antibiotics has resulted in the rapid emergence of antimicrobial resistance (AMR), which is now recognized as a major global public health crisis. According to the World Health Organization (WHO), antimicrobial resistance threatens the effective prevention and treatment of an ever-increasing range of infections, including pneumonia, tuberculosis, septicemia, and wound infections.^[2] Pathogens such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, and *Klebsiella pneumoniae* have developed resistance to multiple classes of antibiotics, rendering many conventional therapies ineffective.^[3]

The situation is particularly alarming in developing countries, where uncontrolled antibiotic usage, self-medication, lack of regulatory oversight, and poor infection control practices accelerate the spread of resistant strains. Hospital-acquired infections caused by multidrug-resistant bacteria significantly increase treatment costs, prolong hospital stays, and elevate mortality rates.^[4] Furthermore, the development pipeline for new antibiotics has slowed considerably due to high research costs, long approval timelines, and low economic returns for pharmaceutical companies.^[5] Consequently, there is an urgent need to explore alternative antimicrobial strategies that are effective, safe, economical, and environmentally sustainable.^[6]

Medicinal plants have played a fundamental role in healthcare systems since ancient civilizations. Traditional systems of medicine such as Ayurveda, Unani, Siddha, and Traditional Chinese Medicine rely heavily on plant-based remedies for the prevention and treatment of various ailments.^[7] Even today, it is estimated that nearly 70–80% of the global population depends on herbal medicines for primary healthcare. Plants synthesize a diverse array of secondary metabolites that serve as defense mechanisms against pathogens, herbivores, and environmental stress. These secondary metabolites—commonly referred to as phytochemicals—include alkaloids, flavonoids, phenolic acids, tannins, terpenoids, saponins, glycosides, and steroid.^[8]

Extensive pharmacological investigations have demonstrated that phytochemicals possess broad-spectrum antimicrobial, antioxidant, anti-inflammatory, anticancer, antidiabetic, and

immunomodulatory properties.^[9] Unlike synthetic drugs that often target a single biochemical pathway, plant-derived compounds frequently exert multitarget effects, reducing the likelihood of resistance development. Moreover, herbal medicines are generally associated with fewer adverse effects and better biocompatibility when used appropriately.^[10] Despite their therapeutic potential, the clinical application of plant extracts faces several limitations, including low bioavailability, poor stability, variability in phytochemical composition, and limited penetration across biological membranes.^[11] These challenges necessitate innovative approaches to enhance the efficacy and delivery of plant-based antimicrobial agents. In the biomedical domain, nanoparticles have been extensively explored for applications such as drug delivery, imaging, diagnostics, tissue engineering, wound healing, and antimicrobial therapy. Metal nanoparticles, in particular, have attracted significant attention due to their potent antimicrobial properties. Metals such as silver, gold, copper, zinc, and magnesium exhibit intrinsic antibacterial activity, which is further amplified at the nanoscale.^[12]

Plant extracts contain a rich repertoire of bioactive compounds that act as natural reducing, capping, and stabilizing agents during nanoparticle formation. Functional groups such as hydroxyl, carbonyl, amine, and carboxyl groups present in phytochemicals facilitate the reduction of metal salts and prevent nanoparticle aggregation.^[13] The resulting nanoparticles are often more stable and biocompatible compared to those synthesized using chemical methods. Green-synthesized nanoparticles integrate the therapeutic properties of both metals and plant phytochemicals, leading to synergistic antimicrobial effects.^[14] This synergy enhances antibacterial potency while minimizing cytotoxicity to host tissues. Furthermore, plant-based synthesis eliminates the need for external stabilizers, reducing production costs and environmental impact.^[15]

Monoon longifolium (commonly known as false Ashoka or Indian mast tree) has been extensively used in indigenous medicine as an antipyretic, antimicrobial, anti-inflammatory, and antioxidant agent. Phytochemical studies have reported the presence of alkaloids, flavonoids, terpenoids, and phenolic compounds in its leaves and bark.^[16] *Ricinus communis* (castor plant) is known for its antimicrobial, anti-inflammatory, and wound-healing properties, attributed to compounds such as ricinoleic acid, flavonoids, and glycosides. *Ficus benjamina*, belonging to the Moraceae family, has been traditionally used for treating skin infections, inflammation, and gastrointestinal disorders.^[17] It contains bioactive compounds such as tannins, saponins, and phenolics. *Sterculia rubiginosa* is less explored but is reported

to possess antimicrobial and antioxidant activities due to the presence of secondary metabolites. Despite their documented medicinal properties, the antimicrobial efficacy of these plants in nanoparticle formulations remains underexplored, particularly in the context of nano-antibiotic development.^[18]

The concept of nano-antibiotics refers to the use of nanoparticles either alone or in combination with antimicrobial agents to inhibit or kill pathogenic microorganisms. Metal nanoparticles such as copper and magnesium have demonstrated broad-spectrum antibacterial activity against both Gram-positive and Gram-negative bacteria.^[19] Copper nanoparticles disrupt bacterial membranes and induce oxidative stress, while magnesium-based nanoparticles interfere with metabolic processes and cellular integrity. When synthesized using plant extracts, these metal nanoparticles exhibit enhanced antimicrobial efficiency due to synergistic interactions between metal ions and phytochemicals. Additionally, nano-antibiotics offer advantages such as controlled release, improved penetration into biofilms, and reduced toxicity compared to conventional antibiotics.^[20] The present study focuses on the green synthesis of metal nanoparticles using extracts of *Monoon longifolium*, *Ricinus communis*, *Ficus benjamina*, and *Sterculia rubiginosa*, and evaluates their antibacterial potential as nano-antibiotics against clinically relevant bacterial pathogens.

2. MATERIALS AND METHODS

2.1 Collection and Preparation of Plant Material: Fresh leaves of *Monoon longifolium*, *Ricinus communis*, *Ficus benjamina*, and *Sterculia rubiginosa* were collected from Kargaina, Bareilly (U.P., India). The samples were washed thoroughly with distilled water, shade-dried, oven-dried, and ground into fine powder for extraction.^[16]

2.2 Preparation of Plant Extracts: Powdered plant material (1g) was extracted using various solvents (methanol, ethanol, chloroform, hexane, petroleum ether, and distilled water). Extracts were incubated for 48 h, filtered, and concentrated by solvent evaporation. Final concentrations were adjusted to 1 mg/mL using dimethyl sulfoxide (DMSO).^[16]

2.3 Microbial Strains: Standard bacterial strains *Staphylococcus aureus* (MTCC 902) and *Pseudomonas aeruginosa* (MTCC 741) were procured from Somics Lifesciences Pvt. Ltd., Bareilly, India. Cultures were maintained on nutrient agar and nutrient broth.^[19]

2.4 Green Synthesis of Metal Nanoparticles: Plant extracts were mixed with metal salt solutions (copper sulphate and magnesium sulphate) and heated at 80°C with continuous stirring. Formation of nanoparticles was indicated by a visible color change. The solutions were dried, reconstituted in DMSO, and stored at -20°C.^[18]

2.5 Antibacterial Activity Assay: Antibacterial activity was evaluated using the agar well diffusion method. Wells were loaded with 500 µg of extracts or nanoparticles. Plates were incubated at 37°C for 24 h, and zones of inhibition (ZOI) were measured. Tetracycline served as the positive control.^[20]

2.6 Minimum Inhibitory Concentration (MIC): MIC was determined by broth dilution method. Serial dilutions of extracts and nanoparticles were incubated with bacterial cultures, and optical density was measured at 600 nm.^[20]

2.7 Phytochemical Screening: Qualitative phytochemical tests were performed to detect flavonoids, tannins, saponins, steroids, terpenoids, and carbohydrates using standard biochemical methods.^[17]

3. RESULTS

The fresh ginger and dried ginger powders were purchased from local area of Subhash Nagar, Bareilly. The fresh Ginger was washed with running tap water, then grinded and converted into thick paste and dried powder was directly mixed with solvent for extract preparation.



Figure 1: Collected samples and its extracted compounds.

Among the four plants studied, *Monoon longifolium* and *Ricinus communis* exhibited notable antibacterial activity. Methanolic and ethanolic extracts showed higher inhibition zones compared to aqueous extracts. Metal nanoparticles synthesized using *Monoon longifolium* demonstrated superior antibacterial efficacy against both test organisms.

Copper nanoparticles exhibited stronger antibacterial activity than magnesium nanoparticles. MIC analysis confirmed lower inhibitory concentrations for nanoparticle formulations compared to crude extracts. Phytochemical analysis revealed the presence of multiple bioactive compounds in *Monoon longifolium*, correlating with enhanced antimicrobial performance. While screening for the antibacterial activities of all extracted compounds from all four plants it was found that Moonon and Ricinus shows effective results.



Figure 2: Nanoparticle synthesis using copper sulfate and magnesium sulphate.

Antibacterial analysis stand for analyzing the antibiotic properties of the extract with different types of polar and non-polar solvents such as methanol, distilled water, chloroform, and ethanol. The studies also revealed that ginger extract with distilled water did not show any antibacterial activity. While ginger extract with methanol shows maximum antibacterial activity as compared to other solvents. After formulating the extract the antibiotic activities increases as compared to tetracycline (positive control) as shown in the figure below

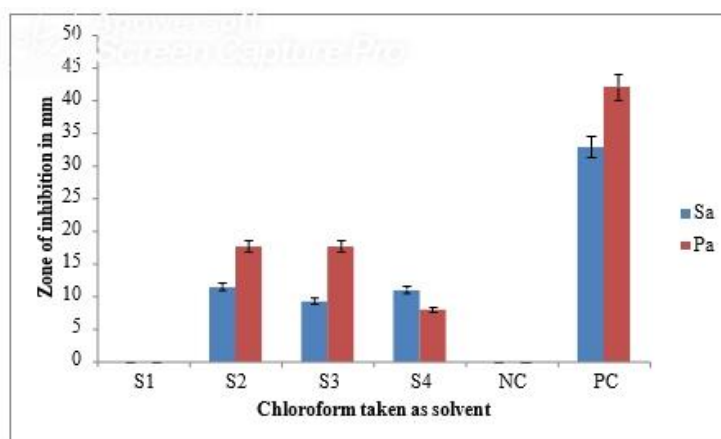


Figure 3: Antibiofilm analysis of chloroform extracts, positive control, negative control, against Pa, Sa.

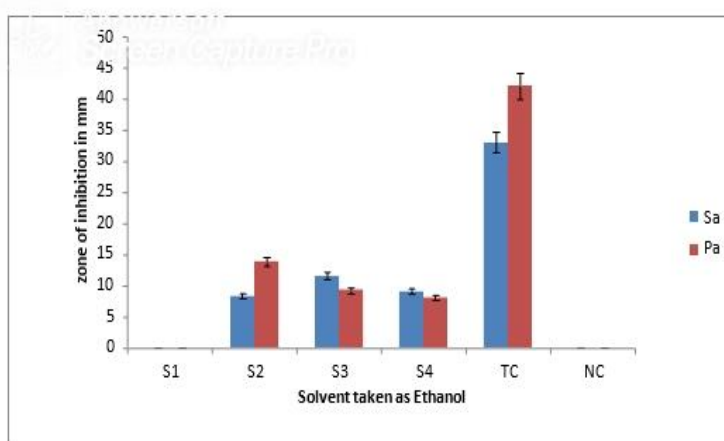


Figure 4: Antibiofilm analysis of hexane extracts, positive control, negative control, against Sa, Pa.

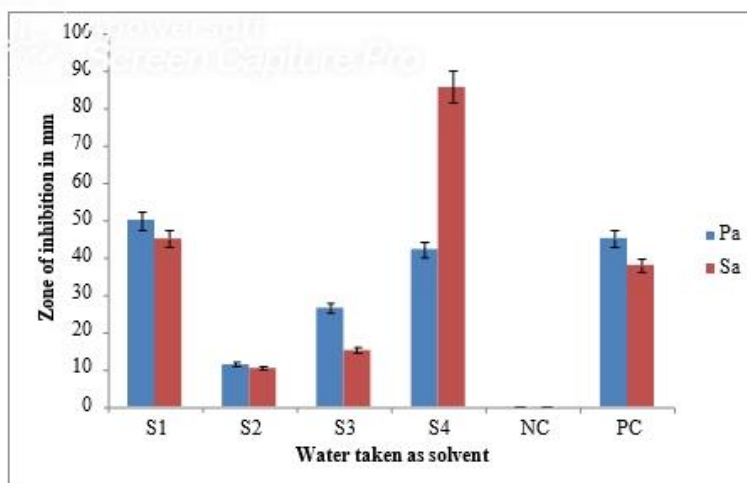


Figure 5: Antibiofilm analysis of methanol extracts, against Pa, Sa.

Table 1: Test for different phytochemical analysis was done and results were observed.

S no.	Phytochemical	Monoon	Ricinus
1.	Steroids	Positive	Negative
2.	Flavonoids	Positive	Negative
3.	Terpenoids	Positive	Negative
4.	Saponin	Positive	Negative
5.	Tanin	Positive	Negative
6.	Carbohydrate	Negative	Positive

The last few years have witnessed a change, with the modernization of the world and advancement in technology we have a great increase in medicines. The disease which were non- curable some year back are now no longer a threat. In fact human race is totally immune to some of disease. New pathogen which is multiple drugs resistant has come into existence. To combat such a scenario we consume loss of medicines antibiotics through they show instant result and we get cured in immune possible time, but these medicines have an adverse effect on us. Prolonged use of such highly dose medicines which are the cure us today make us ill today.

Nature has blessed us with a vast treasure of medicinal plants. Despite giving us fruit to eat wood for fuel lowers for aesthetic beauty all what nature gives us is the gateway to herbal medication it is we who need to discover it and implement in the benefit of human beings and entering in to this gateway I choose four different plants to evaluate its antimicrobial activity and didn't obtained the good results. Then I have prepared the nanoparticles with metal ions and plants extract combination and obtained great results with respect to normal metal salts and crude plant extract. The nanoparticles formed in the ratio of 1:1, shows good antimicrobial properties so then the minimum concentration of that nanoparticle was calculated, which is responsible for the maximum inhibition of the growth.

For finding the phyto-compounds which are present in the plants are qualitatively analyzed with phytochemical tests regarding the phytochemicals.

The enhanced antibacterial activity of plant-mediated metal nanoparticles can be attributed to their nanoscale size and synergistic interaction between metal ions and phytochemicals. Nanoparticles disrupt bacterial cell membranes, generate reactive oxygen species, and interfere with essential cellular processes. The superior activity of *Monoon longifolium*-based nanoparticles highlights the role of flavonoids, terpenoids, and tannins as effective reducing and stabilizing agents. The findings align with previous studies reporting improved

antimicrobial efficacy of green-synthesized nanoparticles over conventional antibiotics. This approach offers a promising strategy to combat antibiotic resistance while minimizing environmental and biological toxicity.

4. CONCLUSION

The present study demonstrates that green synthesis of metal nanoparticles using medicinal plant extracts is an effective and sustainable approach for developing nano-antibiotics. *Monoon longifolium*-mediated copper nanoparticles exhibited significant antibacterial activity against drug-resistant pathogens. These nanoformulations hold strong potential for future biomedical and pharmaceutical applications as alternatives to conventional antibiotics.

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