# Green Synthesis of Silver Nanoparticles from *Myrmecodia pendens* Extract and their Antibacterial Activity against MRSA

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**Abstract.** Methicillin-resistant *Staphylococcus aureus*(MRSA) remains a critical public health concern, underscoring the need for novel antibacterial strategies. Green synthesis of silver nanoparticles (AgNPs) offers an eco-friendly alternative to conventional chemical routes, yet mechanistic insights—particularly phytochemical-driven reduction and ROS-related interactions—are still limited for many medicinal plants, including *Myrmecodia pendens*. This study investigates the use of *Myrmecodia pendens* extract as a reducing and stabilizing agent in microwave-assisted AgNP synthesis and evaluates the antibacterial activity of the resulting AgNPs against MRSA. Antibacterial performance was assessed using a disk diffusion assay, in which disks containing 50 μL of AgNPs-MP were placed on TSA plates inoculated with MRSA and incubated for 24 hours. The microwave-assisted bioreduction rapidly produced uniformly dispersed AgNPs exhibiting a characteristic SPR peak near 420 nm, confirming effective nucleation mediated by plant phytochemicals. All AgNP formulations inhibited MRSA, with inhibition zones ranging from 8.8 to 9.5 mm. Although the 1.5 mM sample produced the largest zone, its difference from the 1 mM formulation remained within typical disk-diffusion variability, indicating comparable activity. These findings demonstrate that *Myrmecodia pendens* enables efficient green synthesis of bioactive AgNPs and supports its potential as a sustainable platform for developing anti-MRSA nanomaterials.

## 1 Introduction

Methicillin-resistant *Staphylococcus aureus*(MRSA) remains a significant worldwide health threat because of its resistance to methicillin as well as a wide range of other β-lactam and non-β-lactam antibiotics [1]. Infections caused by MRSA often lead to severe

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complications involving the skin, bloodstream, bones, joints, and various internal organs, and the rise in antibiotic resistance continues to restrict effective therapeutic options [2]. These circumstances highlight the pressing need for alternative antibacterial approaches capable of reducing the morbidity and mortality linked to MRSA infection [3].

Nanotechnology is increasingly recognized as a valuable pathway for creating advanced antimicrobial solutions [4]. Among the various nanomaterials explored, silver nanoparticles (AgNPs) stand out because of their potent broad-spectrum antibacterial effects, which include disrupting cell membranes, altering protein function, and damaging bacterial DNA—activities frequently linked to the formation of reactive oxygen species (ROS) [5]. Nevertheless, many traditional chemical routes for synthesizing AgNPs depend on harmful reducing agents, raising important concerns about environmental impact, biological safety, and potential cytotoxicity.

These challenges have increased interest in green synthesis methods, which rely on plant-based phytochemicals to act as natural reducing and capping agents [6]. This approach provides greater safety, environmental friendliness, and improved nanoparticle stability, and may even boost antibacterial activity through synergistic interactions among phytochemicals. Medicinal plants containing high levels of flavonoids, tannins, alkaloids, and other bioactive molecules have shown strong capability in producing well-dispersed AgNPs under eco-friendly synthesis conditions [6].

*Myrmecodia pendens* (Sarang Semut), an Indonesian medicinal plant traditionally used for antimicrobial and antioxidant purposes, contains abundant phytochemicals with known reducing and stabilizing capabilities [7]. Despite its therapeutic relevance, the ability of *M. pendens* to mediate AgNP synthesis—and the mechanistic contributions of its bioactive compounds to nanoparticle formation and antibacterial activity—has not been previously investigated.

To address this gap, the present study evaluates *M. pendens* extract as a dual-function bioreductant and capping agent for the microwave-assisted green synthesis of AgNPs. The study further examines how precursor concentration influences nanoparticle size, dispersion characteristics, and antibacterial activity against MRSA. By elucidating the role of plant-derived phytochemicals and potential ROS-associated pathways, this work aims to advance sustainable nanotechnology-based strategies for combating MRSA and other antibiotic-resistant pathogens.

## 2 Materials and Methods

### 2.1 Preparation of *Myrmecodia pendens* Extract

A total of 0.5 g of powdered *Myrmecodia pendens* was mixed with 45 mL of distilled water and subjected to microwave heating at 90 W for 10 minutes. After heating, the mixture was passed through Whatman No. 1 filter paper to obtain a clear aqueous extract. This extract was subsequently used as the reducing and stabilizing agent in the nanoparticle synthesis process.

### 2.2 Green Synthesis of Silver Nanoparticles (AgNPs-MP)

Silver nanoparticles were produced using silver nitrate ($AgNO_3$) as the precursor and *M. pendens* extract as the natural reducing agent. Three $Ag^+$ concentrations—1 mM, 1.5 mM, and 2 mM—were employed to assess how precursor levels affect nanoparticle formation and size distribution. In each synthesis run, 45 mL of $AgNO_3$ solution was combined with 5 mL of the plant extract in an Erlenmeyer flask, covered with aluminum foil, and then exposed to microwave irradiation at 180 W for 40 minutes. The progression of bioreduction was confirmed by the appearance of a uniform yellowish-brown color. Measurements of post-synthesis pH and quantitative yield (mg $Ag^0$ per mg $AgNO_3$) were not performed.

The UV–Vis absorption profiles of the AgNPs-MP samples were obtained using a Shimadzu UV-Vis 1800 spectrophotometer. The nanoparticle size distribution was analyzed with a Particle Size Analyzer (PSA) employing the Dynamic Light Scattering (DLS) technique.

### 2.3 Bacterial Culture

Methicillin-resistant *Staphylococcus aureus*(MRSA) was cultivated in Tryptic Soy Broth (TSB). For the culture preparation, 0.3 g of TSB was dissolved in 10 mL of distilled water, autoclaved for sterilization, inoculated with a loopful of MRSA, and then incubated at 37 °C for 24 hours until the suspension reached the 1.0 McFarland turbidity standard. The reference strain *S. aureus* ATCC was used for comparison.

### 2.4 Antibacterial Activity Assay

The antibacterial effects of AgNPs-MP were evaluated using the disk diffusion assay. A 50 µL portion of the standardized MRSA inoculum was evenly spread across Tryptic Soy Agar (TSA) plates. Sterile paper disks were then saturated with 50 µL of the AgNPs-MP solution, allowed to dry, and placed on the surface of the inoculated agar. Following incubation at 37 °C for 24 hours, antibacterial activity was determined by measuring the diameter of the inhibition zones formed around each disk.

## 3 Results

The silver nanoparticles synthesized using *Myrmecodia pendens* extract developed a characteristic golden-yellow appearance, as shown in Figure 1. Their UV–Vis absorbance profile is depicted in Figure 2, with measurements recorded across wavelengths ranging from 325 nm to 650 nm. The extract alone exhibited an absorbance range of approximately 348–619 nm, whereas the AgNPs generated from the extract displayed a distinct peak at 420 nm. An absorption maximum (λ_max) between 400–450 nm is indicative of silver nanoparticle formation, while λ_max values between 300–400 nm correspond to $Ag^+$ ions. Based on this theoretical interpretation, the formation of silver nanoparticles was confirmed, and their exact size was subsequently verified through Particle Size Analysis (PSA).

### 3.1 Synthesis and Visual Observation

The silver nanoparticles synthesized using *Myrmecodia pendens* extract exhibited a uniform golden-yellow coloration, indicating successful bioreduction of $Ag^+$ ions (Figure 1).

**Fig. 1.** Synthesis of Silver Nanoparticles from *Myrmecodia pendens* Extract.

### 3.2 UV Vis Spectroscopy

Figure 2 presents the UV–Vis absorbance profiles of AgNPs-MP synthesized using 1 mM, 1.5 mM, and 2 mM precursor concentrations. Spectral data were collected across wavelengths from 325 to 650 nm. Each formulation exhibited a distinct surface plasmon resonance (SPR) band near 420 nm, confirming the successful formation of silver nanoparticles. Meanwhile, absorbance detected in the 300–400 nm region corresponded to remaining $Ag^+$ ions. These spectral characteristics indicate that AgNPs-MP were successfully generated, after which their particle sizes were further analyzed using Particle Size Analysis (PSA).

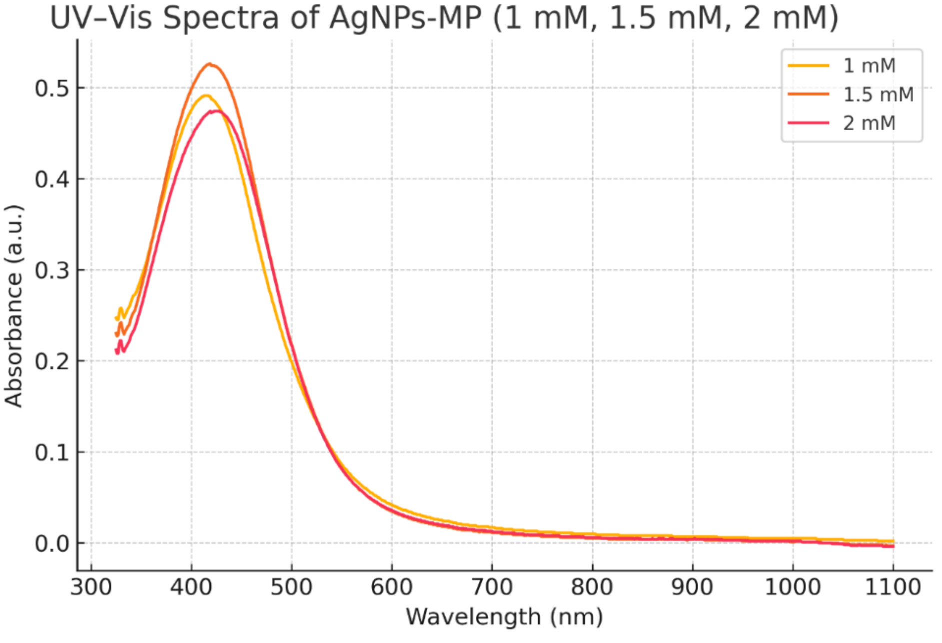

**Fig. 2.** UV–Vis absorption profiles of AgNPs-MP prepared at 1 mM, 1.5 mM, and 2 mM, each displaying a distinct SPR band centered around 420 nm

### 3.3 Particle Size Distribution (DLS/PSA Analysis)

The findings from the particle size measurements are presented in Table 1 and depicted in Figure 3. The AgNPs-MP produced using precursor concentrations of 1 mM, 1.5 mM, and 2 mM had mean particle sizes of 24.59 nm, 20.59 nm, and 16.69 nm, respectively. The polydispersity index (PDI) values, which ranged between 0.133 and 0.143, reflect narrow size distributions and a high degree of sample uniformity. Additionally, the DLS volume distribution curves demonstrated that higher precursor concentrations yielded smaller nanoparticles with tighter size dispersion.

**Table 1.** Average Particle Diameter and Polydispersity Index of Silver Nanoparticles Synthesized from *Myrmecodia pendens* Extract

| Silver Nanoparticle Synthesis | Concentration (mM) | Average Diameter (nm) | Polydispersity Index |
|---|---|---|---|
| AgNPs from *Myrmecodia pendens* Extract | 1 | 24.59 | 0.133 |
| | 1.5 | 20.59 | 0.143 |
| | 2 | 16.69 | 0.137 |

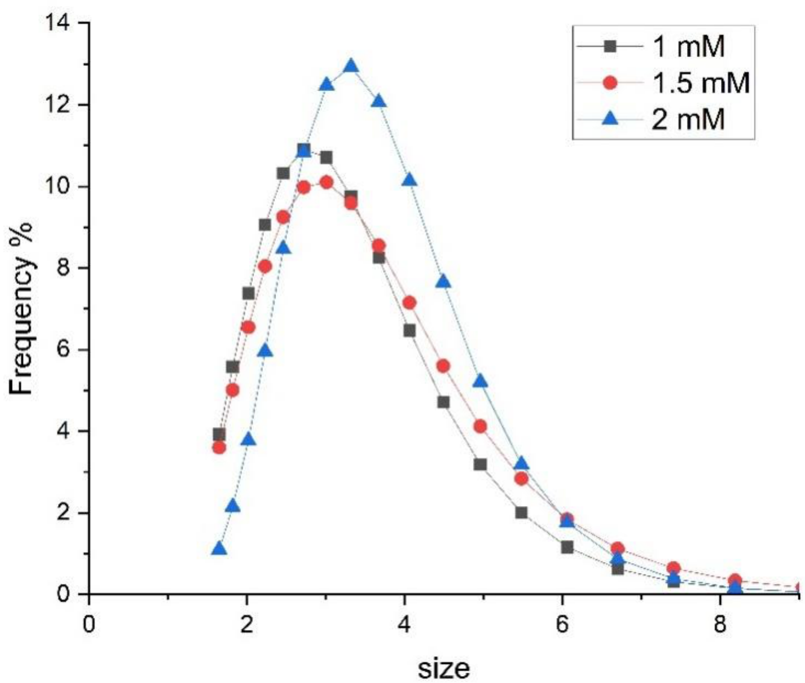


**Fig. 3.** Particle Size Analysis (PSA) profiles of AgNPs-MP synthesized using precursor concentrations of 1 mM, 1.5 mM, and 2 mM

### 3.4 Antibacterial Activity Against MRSA

The antibacterial properties of AgNPs-MP were assessed through the disk diffusion method (Figure 4). All nanoparticle formulations exhibited clear inhibitory effects against MRSA. The measured inhibition zone diameters for the 1 mM, 1.5 mM, and 2 mM AgNPs-MP samples were 9.25 mm, 9.50 mm, and 8.80 mm, respectively, demonstrating the effective antimicrobial activity of the synthesized nanoparticles.

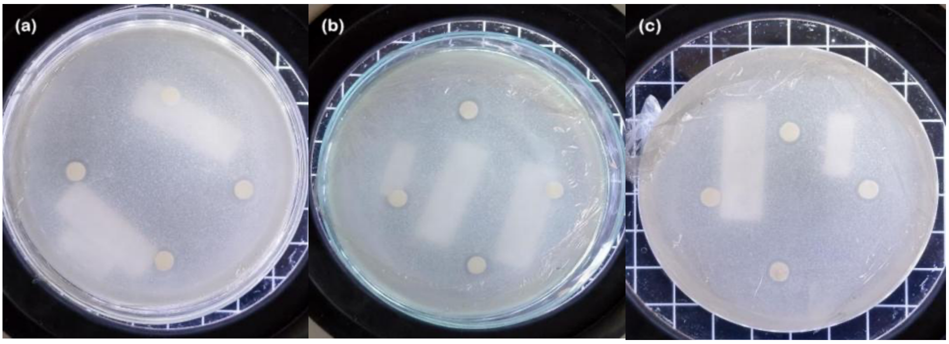


**Fig. 4.** Disk diffusion assay showing the antibacterial response of MRSA to AgNPs-MP synthesized at concentrations of (a) 1 mM, (b) 1.5 mM, and (c) 2 mM.

## 4 Discussion

Methicillin-resistant *Staphylococcus aureus*(MRSA) continues to pose a significant clinical threat because of its broad resistance to β-lactam antibiotics and numerous other antimicrobial categories. This challenge has increased interest in plant-based reducing and stabilizing compounds for environmentally friendly synthesis of antibacterial nanomaterials. In the present study, Myrmecodia pendens extract—known to contain abundant polyphenols, flavonoids, tannins, and alkaloids—was utilized as both a natural reducing agent and a stabilizer in the microwave-assisted fabrication of silver nanoparticles (AgNPs-MP).

The successful synthesis of AgNPs-MP was indicated by the development of a yellowish-brown color as well as the presence of a clear surface plasmon resonance (SPR) band at approximately 420 nm, a signature of spherical silver nanoparticles with minimal remaining $Ag^+$ ions. Particle size measurements showed nanoscale diameters between 16.69 and 24.59 nm, accompanied by low PDI values (0.133–0.143), demonstrating that the nanoparticles were uniformly dispersed. Together, these results confirm the strong capability of *M. pendens* phytochemicals to facilitate nanoparticle nucleation and maintain colloidal stability.

Although smaller nanoparticles typically exhibit stronger antibacterial effects, the 2 mM sample—which generated the smallest particle size—showed the weakest inhibition zone. This non-linear trend suggests that the antibacterial performance in this system is influenced not only by particle diameter but also by factors such as surface chemistry, capping layer density, colloidal stability, and the nanoparticles' diffusion characteristics within the agar medium.

### 4.1 Mechanistic Interpretation of MRSA Inhibition

AgNP-mediated antibacterial activity is known to involve multiple, synergistic pathways that collectively compromise bacterial viability. The results of this study can be interpreted through the following mechanistic framework:

1. Compromise of cell wall and membrane integrity

AgNPs adsorb onto the MRSA cell wall via electrostatic interactions and penetrate the thick Gram-positive peptidoglycan layer. This interaction induces membrane destabilization, pore formation, and increased permeability, resulting in leakage of ions and intracellular metabolites and rapid loss of homeostasis.

2. Release of $Ag^+$ Ions and Targeting of Thiol-Rich Proteins

Even under capping, AgNPs release $Ag^+$ ions that bind strongly to thiol (-SH) groups in essential bacterial enzymes. This disrupts cell-wall biosynthesis, protein folding, and metabolic pathways—particularly oxidative phosphorylation—ultimately impairing cellular function and viability [8].

3. Induction of reactive oxygen species (ROS) formation

AgNPs facilitate the generation of reactive oxygen species (ROS), such as superoxide and hydroxyl radicals, which induce oxidative damage to membrane lipids, structural proteins, and nucleic acid [9]. At higher precursor concentrations, the resulting nanoparticles may possess thicker phytochemical capping layers that either scavenge ROS or limit $Ag^+$ ion release, helping to explain the lower antibacterial activity observed at 2 mM.

4. Interaction with DNA and Inhibition of Replication

Nanoparticles can penetrate the cytoplasm and interact with bacterial DNA, inducing structural deformation and inhibiting replication and transcription [8]. This disruption of genetic processes contributes significantly to the bactericidal activity of nanosilver.

5. Interference with the Respiratory Chain

AgNPs can impair electron transport chain components, decreasing ATP production. Energy depletion weakens bacterial stress responses and accelerates cell death [10].

### 4.2 Interpretation of Non-Linear Antibacterial Activity

Although smaller nanoparticles generally display higher antibacterial activity, the lowest inhibition zone at 2 mM suggests competing physicochemical effects:

1. Secondary agglomeration: small particles may cluster into larger aggregates that diffuse poorly in agar.
2. Excess capping: higher organic content may reduce $Ag^+$ release and ROS generation.
3. Ionic-strength effects: denser ionic environments may restrict radial diffusion in agar assays.

Thus, antibacterial performance in this system is likely determined by the combined effects of particle size, surface chemistry, and medium-dependent diffusion, rather than particle size alone. The comparable activity between 1 and 1.5 mM (difference = 0.25 mm) lies within the expected variability of disk diffusion assays, indicating similar effectiveness across these concentrations.

Several studies on plant-mediated synthesis of AgNPs provide quantitative benchmarks for comparison. Green-synthesized AgNPs using *Azadirachta indica* typically range 20–35 nm and yield MRSA inhibition zones of 10–12 mm at similar concentrations (11). AgNPs produced from *Camellia sinensis* report sizes of 18–30 nm with inhibition zones of 9–11 mm. The AgNPs-MP synthesized in this study fall within a comparable nanoscale range (16.69–24.59 nm), with antibacterial activity (8.8–9.5 mm) slightly lower but still within reported ranges [12].

AgNPs derived from *Iris tuberosa* have been reported to produce inhibition zones of 9–11 mm with particle sizes of 20–40 nm [13]. Compared with these, *M. pendens* generated smaller and more uniform nanoparticles, although the antimicrobial activity was modestly lower. This difference may be attributed to phytochemical composition influencing $Ag^+$ ion release and ROS generation.

The smallest particles (2 mM) did not yield the highest inhibition zone, a phenomenon consistent with findings using *Ocimum sanctum* [14] and *Aloe vera* [15], where excessive capping limited $Ag^+$ availability despite reduced particle size. This supports the notion that antibacterial performance is governed by surface reactivity and capping density rather than size alone. The nanoparticle sizes obtained (16–24 nm) are consistent with reports using phenolic-rich extracts such as *Azadirachta indica* and *Camellia sinensis*. The inhibition zones observed (8.8–9.5 mm) align with those reported for Myrmecodia-derived AgNPs and fall within the typical range for plant-mediated nanosilver systems. However, the concentration-dependent mechanistic behavior observed in this study highlights the unique influence of *M. pendens* phytochemicals on nucleation kinetics, capping layer architecture, and ROS-associated antibacterial pathways.

Overall, the findings demonstrate that *M. pendens* extract enables rapid synthesis of stable, bioactive AgNPs with measurable anti-MRSA activity mediated by combined mechanisms of membrane disruption, $Ag^+$ release, ROS generation, and interference with essential cellular processes. The results also underscore the complexity of concentration-dependent behavior in green-synthesized nanoparticles, emphasizing the need to optimize not only particle size but also surface chemistry and colloidal stability.
Future work incorporating TEM, zeta potential, FT-IR, and $Ag^+$ release quantification will provide deeper insight into nanoparticle–bacteria interactions. Assessments of cytotoxicity, long-term stability, and synergistic effects with antibiotics will further support the development of AgNPs-MP as a sustainable antimicrobial nanomaterial.

## 5 Conclusion

This study confirms that *Myrmecodia pendens* extract functions effectively as both a bioreductant and capping agent for the rapid microwave-assisted synthesis of silver nanoparticles, producing uniform particle sizes with notable antibacterial activity against MRSA. The concentration-dependent trends observed in AgNPs-MP underline the interplay between particle size, surface properties, and colloidal stability in determining antibacterial efficacy. Overall, these results demonstrate the potential of *M. pendens*–based AgNPs as a sustainable nanomaterial platform and highlight the need for further studies on cytotoxicity, $Ag^+$ ion release, and possible synergistic effects with antibiotics.

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