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Studying the Antimicrobial Effects of Silver Nanoparticles (AgNPs) Derived from the Agricultural Byproduct of *Rhus coriaria* L. (Sumac)

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Abstract
The synthesis of nanoparticles using green methods is attracting increasing interest due to its wide range of applicationsThis research used an extract from the leaves, which are agricultural waste parts after the of *Rhus coriaria* L. fruit harvest to create silver nanoparticles (AgNPs). Analyses utilising X-ray diffraction diffractometry (XRD), UV-visible spectrophotometer (UV-vis.), and scanning electron microscopy (SEM) were used to characterise AgNPs. Results showed that the produced AgNPs had a spherical shape, a maximum absorbance of 367.47 nm, and crystalline nanoscale dimensions of 63.57 nm. The created AgNPs were tested for their antibacterial properties using microdilution methods on gram-positive and gram-negative bacteria, as well as the yeast *C. albicans* ATCC 10231. According to the study's findings, the synthesised AgNPs demonstrated strong antibacterial activity at concentrations of 0.75 and 1.50 µg mL^{-1}.

Research Article

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1. Introduction

Nanoparticles, with a nanoscale size ranging from 1 to 100 nm, are particles that possess high catalytic activity, thermal conductivity, chemical stability, and a large surface area. Nanoparticles are used on a wide scale in industries including biomedical, food, aerospace, healthcare, cosmetics, and chemicals. Nanoparticles are synthesized in two ways: either by a top-down approach or a top-up approach. Nanoparticles can be synthesized using different methods (biological, physical, and chemical) (Zulfiqar et al., 2024). Unlike biological synthesis methods, physical and chemical synthesis methods have become less preferred in recent years due to their high costs, the necessity of using toxic chemicals, and their negative impacts on health and the environment, in addition to the need for very high temperature and pressure processes (Arshad et al., 2024). In recent years, nanoparticle synthesis studies have made biological methods more attractive for synthesis applications due to their biocompatibility, environmental friendliness, ease of use, and economic advantages. Plant sources, bacteria, algae, and various fungi are used for these methods (Mejía-Méndez et al., 2023; Mohamed et al., 2025). Green synthesis methods, which utilize plant resources, are low-cost because they do not require special conditions or high energy consumption. Furthermore, the fact that waste parts of plant resources, such as leaves, fruit peels, or seed shells, can be used for synthesis, along with the beneficial use of recycling, is increasing interest in this field every day. This is because the synthesis of nanoparticles obtained through green synthesis methods does not involve the use of toxic chemicals from an environmentally friendly perspective, and their biocompatibility for medical applications makes them particularly preferred for various applications (Arshad et al., 2024). Among the nanoparticles, metallic AgNPs, such as gold nanoparticles and iron nanoparticles, are preferred for medical applications. AgNPs are suitable nanomaterials for various medical applications, particularly due to their antimicrobial effects. Medical applications focus on the cancer-preventive, antioxidant, anti-inflammatory, and antimicrobial activities of AgNPs. Active compounds such as phenolic acids, flavonoids, and alkaloids found in plant-derived extracts play an effective role in obtaining these valuable nanoparticles. These compounds, in an aqueous environment, reduce ionized silver (Ag^{+1}) through redox reactions, thereby synthesizing the Ag^{0} form, i.e., AgNPs. Furthermore, these active components also contribute to stability and coating (Vadakkan et al., 2024; Sharifi-Rad et al., 2024). *Rhus coriaria* L. is a member of the Anacardiaceae family. The wild fruits of the plant are some of the most neglected and underutilized species in the Mediterranean region. These plants have a long history of use in spices, food, and traditional medicine. In some cases, they are also used in the production of certain products such as dyes and cosmetics (Perrone et al., 2022). *Rhus coriaria* L. (*R. coriaria*), commonly known as sumac, has received increasing attention in recent years due to its therapeutic results. Due to the presence of phytochemical compounds such as flavonoids, phenolic acids, and tannins, sumac is attributed many health benefits, including anti-cancer, antimicrobial, antioxidant, anti-inflammatory, hypoglycemic, antifungal, neuroprotective, hypolipidemic, and antiatherogenic properties (Perrone et al., 2022; Mongy and Shalaby, 2024). The aim of this study is to determine the environmentally friendly, low-cost synthesis, characterization, and antimicrobial activity of AgNPs from the extract obtained from the leaves of sumac (*R. coriaria*), which is an agricultural waste product after fruit harvesting.

2. Material and Methods

2.1. Plant extract and metal solution preparation process

The leaves of *R. coriaria*, agricultural waste obtained from a local plant vendor on the Midyat road in Batman, were washed several times with tap water and distilled water to remove impurities, and then dried at room temperature. 150 g of dried *R. coriaria* leaves were weighed and mixed with 450 mL of distilled water in a 1000 mL container. This

mixture was then placed on a heater and heated until boiling. It was left to stand for about 10 minutes. After cooling the hot mixture to room temperature, it was filtered through a filter paper to obtain the extract, which was then stored in a refrigerator at +4 °C for use in the synthesis of AgNPs. A metal solution was prepared using Sigma brand silver nitrate ($AgNO_3$) salt at a concentration of 40 mg L^{-1}.

2.2. Bioreduction synthesis of AgNPs from extract obtained from non-consumable waste parts of *R. coriaria* plant

The extract obtained from *R. coriaria* leaves and a 40 mg L^{-1} $AgNO_3$ solution were mixed in a 4:1 ratio and incubated at 30 °C. The maximum wavelength absorbances of samples taken from the reaction medium were measured using UV-vis by observing the color change. During the synthesis process, typical maximum wavelength absorbances of AgNPs obtained from the extract of non-edible waste parts of the *R. coriaria* (RC*AgNPs) plant were evaluated by taking measurements at different time intervals (Scheme 1).

2.3. Characterization of RC*AgNPs

Microscopic and spectroscopic techniques were used to evaluate the morphological structures and dimensional distributions of the synthesized RC*AgNPs. For morphological analysis, a Jeol Jem 1010 Transmission Electron Microscope (TEM) and a LEO-EVO 40/Cambridge-UK Scanning Electron Microscope (SEM) were used. For elemental profiling, a Bruker-125 eV (Berlin-Germany) Energy Dispersive X-ray (EDX) and for crystal pattern determination, a Rigaku-D/Max 2200 (Tokyo, Japan) X-ray diffraction (XRD) were used.



Scheme 1. Representative illustration of the synthesis of AgNPs obtained from the extract of inedible waste parts of the *R. coriaria* plant

2.4.Antimicrobial effects of RC*AgNPs for medical applications

The inhibitory effects of RC*AgNPs on the growth of pathogenic strains were investigated using the microdilution method (Sarker et al., 2007; Zapata and Ramirez-Arcos, 2015). The strains used in the applications were obtained from Mardin Artuklu University. Varying concentrations of RC*AgNPs were prepared. The pathogenic bacteria Escherichia coli ATCC 11229 (*E. coli*) and *Staphylococcus aureus* ATCC 29213 (*S. aureus*), along with the yeast *C. albicans* ATCC 10231 (*C. albicans*), were cultured in suitable media, namely nutrient agar and sabora dextros agar, respectively, in an incubator at 37 °C for 24-48 hours. At the end of this period, the turbidity criterion of each microorganism growing in the culture media was adjusted to the McFarland standard of 0.5 (Gayathiri et al., 2018) and made ready for applications. Müller Hinton and Roswell Park Memorial Institute (RPMI) 1640 liquid media were pipetted into microplates for bacteria and *C. albicans*, respectively Stock solutions containing RC*AgNPs at a concentration of 96 mg L^{-1} were prepared. RC*AgNPs prepared from these stock solutions were pipetted into wells and subjected to a series of microdilution procedures. Then, the prepared microorganism suspensions were added and incubated at 30-37 °C to allow interaction. After interaction, the Minimum Inhibitory Concentration (MIC) was determined (Baran, 2025).

3. Results and Discussion

3.1. Characterization data of RC*AgNPs

After mixing the extract prepared from the leaf parts of the *R. coriaria* plant with 40 mlL^{-1} Ag metal solution, a color change from yellow to brown was observed within two hours. The color change from yellow to brown and the maximum absorbance bands at 367.47 nm obtained in UV-vis measurements due to this formation were characteristic data indicating the formation of RC*AgNPs as a result of vibrations (SPR) occurring on the plasma surface (Figure 1) (Essghaier et al., 2023; Nosrati et al., 2025).

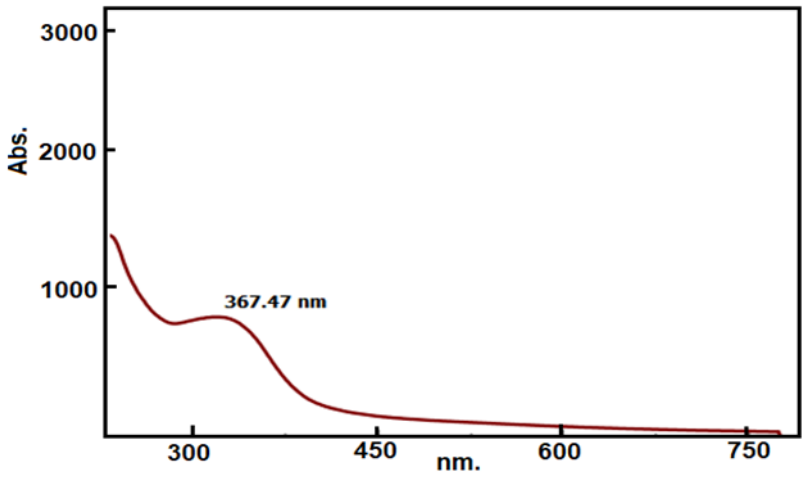


Figure 1. Maximum absorbance spectra obtained at the characteristic wavelength of 367.47 nm, measured from UV-vis, showing the formation of RC*AgNPs (SPR-dependent)

Figures 2a and 2b show microscopic images illustrating the morphology of RC*AgNPs. The micrographs show that the synthesized RC*AgNPs have a spherical appearance. Previous studies have included microscopic images supporting the morphology of RC*AgNPs obtained from TEM and SEM micrographs. The spherical morphology of AgNPs synthesized via Lallemantia royleana was shown in TEM images (Sharifi-Rad et al., 2024). Micrographs showing spherical morphological grooves in AgNPs obtained from *Clarias gariepinus*, as observed in SEM and TEM microscopy, were presented (Alabssawy et al., 2024).

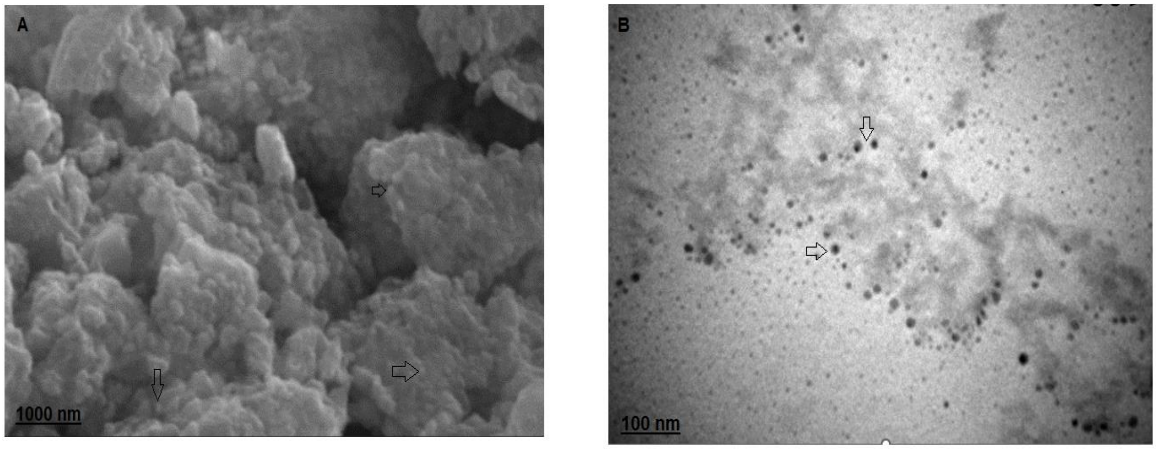


Figure 2. (a) SEM and (b) TEM micrographs showing the morphological appearance of RC*AgNPs

Data from EDX measurements of RC*AgNPs given in Figure 3a show that strong silver peaks were successfully obtained from RC*AgNPs. The presence of weak oxygen (O) and carbon (C) peaks reflected in the elemental composition was indicative of the presence of phytochemicals on the surface of AgNPs synthesized via the extract of non-consumable leaves of *Rhus coriaria* L. (Rengarajan et al., 2024; Khan et al., 2024).

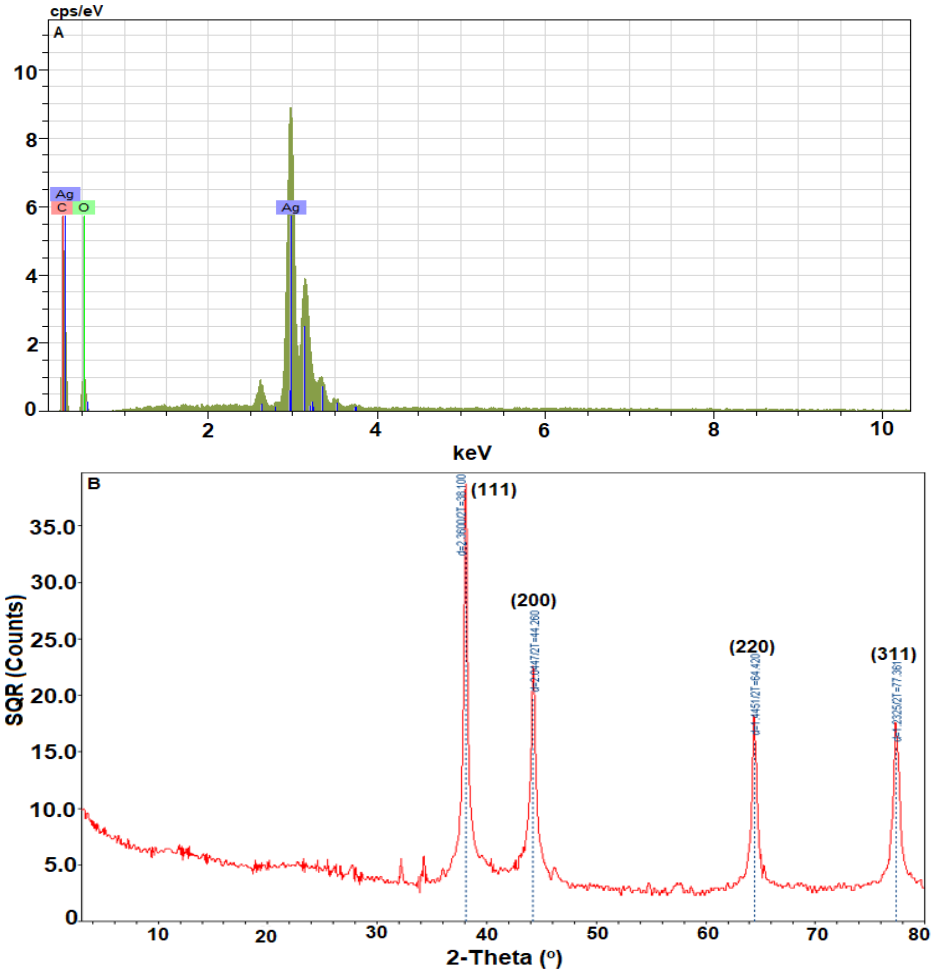


Figure 3. (a) EDX profile and (b) XRD pattern showing the elemental compositions and crystal structures of RC*AgNPs

The crystal structure data of RC*AgNPs, obtained at 2θ, are given in Figure 3b. The data show that the expansions at Bragg's angles of 111°, 200°, 220°, and 311° were characteristic points for silver. The crystal nanosizes were calculated using the Debye-Sherer equation, using the FWHM value of the RC*AgNP with the maximum height at the Bragg's angles and a center-faced cubic (fcc) crystal pattern (Baran, 2025). Furthermore, the synthesized RC*AgNPs were compatible with silver, JCPDS card no. 01-080-1439 (Rengarajan et al., 2024; Mohamed et al., 2025). Calculations revealed that the synthesized RC*AgNPs had crystal nanoscale dimensions of 63.57 nm. AgNPs synthesized with Cucurbita Maxima L. were calculated to be 67 nm and 56 nm using the Debye-Sherer equation (Ali, 2020).

3.2. Antimicrobial effects of RC*AgNPs

The antimicrobial effects of the synthesized RC*AgNPs were investigated using the microdilution method. As shown in Table 1, Figure 4, the MIC range that suppresses the growth of the pathogen strains used in the application was determined to be 0.25-1.50 µg mL^{-1}. These effects were quite low compared to antibiotic and AgNO3 solutions. The data show that RC*AgNPs exhibited the most effective antimicrobial activity at low concentrations against *C. albicans* (0.25 µg mL^{-1}). Concentrations of 0.75 and 1.50 µg mL^{-1}, respectively, were more successful against *E. coli* and *S. aureus* compared to antibiotic and $AgNO_3$ solutions. In a study on the antimicrobial activity of combinations of AgNPs synthesized via *Clarias gariepinus*, the MIC value was determined to be 2.5 µg mL^{-1} against *C. albicans* and *S. aureus* (Alabssawy et al., 2024). It was stated that AgNPs synthesized using *Lallemantia royleana* showed antimicrobial activity against *S. aureus* and *E. coli* with MIC values of 37.5 and 75 µg mL^{-1}, respectively (Sharifi-Rad et al., 2024). AgNPs exert their antimicrobial effects by increasing ROS formation through their interaction with living organisms, or by causing structural and functional disruptions in many processes such as cell membranes and metabolic activities. This may be due to the physicochemical properties of the synthesized RC*AgNPs, such as size, surface chemistry, and morphological appearance. Because properties such as size and morphological structure play a decisive role in antimicrobial activity (Salem et al., 2022; Sharifi-Rad et al., 2024). In this study, it was determined that the obtained RC*AgNPs showed antimicrobial activity at lower concentrations compared to previous studies.

Table 1. MIC values of RC*AgNPs obtained from synthesis, $AgNO_3$ and antibiotic solutions as a result of antimicrobial effects

Microorganisms			$AgNO_3$ Solution	Antibiotic	RC*AgNPs
			Concentrations (µg mL^{-1})		
Bacteria	Gram structure	Strains			
	-	*E. coli*	2.10	4.00	0.75
	+	*S. aureus*	1.05	2.00	1.50
Fungii (Yeast)	+	*C. albicans*	0.52	1.00	0.25

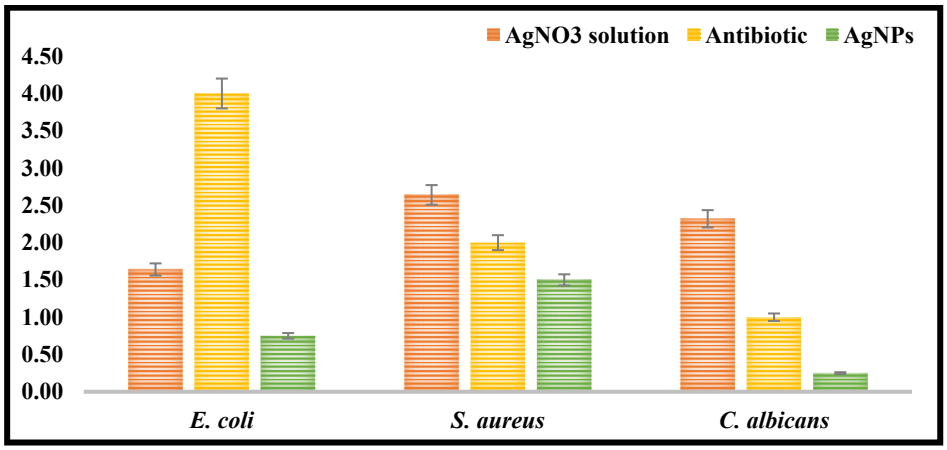


Figure 4. MIC ratios resulting from the antimicrobial effects of RC*AgNPs, $AgNO_3$, and antibiotic solutions on pathogenic strains

4. Conclusion

The range of uses of AgNPs makes them a very desirable commodity. For this study, researchers synthesised RC*AgNPs from Rhus coriaria L.'s non-consumable leaf extract and characterised them using data from SEM, UV-vis, XRD, TEM, and EDX. The fungal strain *C. albicans*, gram-positive and gram-negative bacteria, and the synthesised RC*AgNPs were tested for their antibacterial activity. Research indicated that at concentrations of 0.75 and 1.50 µg mL^{-1}, the synthesised AgNPs exhibited more potent antibacterial activity when tested against antibiotics and silver nitrate solution. Since RC*AgNPs have the ability to serve as antimicrobial agents that are required in numerous domains, studying their impacts in living organisms is thought to be very beneficial.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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Ethical Committee Approval

This study did not involve human or animal subjects; therefore, ethical approval was not required.

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