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ECO-FRIENDLY SYNTHESIS OF SILVER NANOPARTICLES USING APPLE PEEL EXTRACT

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Article Info

Abstract

The increase of antibiotic resistance has motivated the pursuit for alternative, environmentally friendly antimicrobial agents. This study reveals the green synthesis of silver nanoparticles (AgNPs) using *Malus domestica* (apple) peel extract, which performances as a natural reducing and stabilizing agent. A distinct color transformation from yellow to brown designated AgNP formation, further confirmed by UV–Vis spectroscopy at 412 nm. The synthesized AgNPs were tested against *Escherichia coli* and *Klebsiella pneumoniae*, as well as the fungi *Aspergillus flavus* and *Aspergillus niger*. Results indicated strong antimicrobial activity in a dose-dependent manner. These results offer a sustainable approach for converting fruit waste into biocompatible nanomaterials with strong potential in remedial and ecological fields.

Keywords:

Green synthesis, silver nanoparticles, apple peel extract, antibacterial, antifungal, sustainable nanotechnology

1. INTRODUCTION

Nanotechnology has appeared as a multidisciplinary field that meets chemistry, biology, physics, materials science, and engineering, with applications across healthcare, environmental science, agriculture, and energy. Nanoparticles, predominantly metallic ones such as silver nanoparticles (AgNPs), have drawn significant attention due to their remarkable properties, including high surface-area-to-volume ratio, tunable optical characteristics, and potent organic activities [1,2].

Silver nanoparticles are well-known for their broad-spectrum antimicrobial properties, proficient of acting against bacteria, fungi, and viruses. These properties make AgNPs highly attractive for use in wound dressings, medical instruments, wrapping materials, and water purification systems [3,4]. The mechanism of their antimicrobial action includes the generation of reactive oxygen species (ROS), distraction of microbial cell walls and membranes, interaction with DNA and proteins, and hangup of essential enzymatic pathways [5,6,7].

Despite their verified efficacy, conventional synthesis methods for AgNPs involve harmful chemicals such as sodium borohydride, hydrazine, and ethylene glycol, which pose environmental and biological hazards. Besides, these methods often need high energy input and complex apparatus, making them less sustainable [8,9]. To overcome these tasks, green synthesis has developed as a feasible and environmentally friendly alternative that utilizes biological units— such as plants, fungi, bacteria, and algae—to mediate the reduction and stabilization of silver ions [10].

Plant-based green synthesis, in particular, offers numerous advantages. It is cost-effective, scalable, and removes the need for maintaining microbial cultures. Plants are rich in a diverse range of secondary metabolites, including polyphenols, alkaloids, terpenoids, flavonoids, and tannins, which can serve as reducing and capping agents in nanoparticle formation [11]. Among plant-based materials, fruit peels are a rich and underutilized resource that contain high levels of phytochemicals and antioxidants.

Pomegranate (*Punica granatum*) peel extract, for example, has been successfully used in the synthesis of AgNPs, as proved by Leghari et al. (2025), who reported spherical nanoparticles with outstanding antibacterial properties [12]. Encouraged by such studies, this research focuses on the green synthesis of AgNPs using Malus domestica (apple) peel extract—a readily available agricultural leftover rich in antioxidants such as quercetin, catechins, chlorogenic acid, and phloridzin [13,14,15]. Apple peel extract offers both environmental and economic benefits by reducing biowaste and removing poisonous reagents.

Several studies have already confirmed the effectiveness of plant extracts in nanoparticle synthesis, such as banana [16], neem [17], lemon [18], and mango peels [19]. These bioresources exhibit appropriate reducing capacity to convert silver ions into stable nanoparticles. However, few studies have systematically evaluated apple peel extract for its antimicrobial efficacy in both antibacterial and antifungal contexts.

This study aims to link that gap by synthesizing silver nanoparticles using apple peel extract, characterizing the nanoparticles using UV-Vis spectroscopy, and evaluating their antimicrobial potential against clinically relevant pathogens. The novelty lies not only in utilizing apple peels but also in providing

comparative analysis and insight into their role as green nanomaterial precursors, similar to pomegranate and other fruit-based sources.

In addition to selecting environmentally friendly reducing agents, the effectiveness of nanoparticle synthesis is significantly influenced by experimental parameters such as temperature, pH, reaction time, and alkaline medium. Among these, NaOH plays a critical role in facilitating the reduction of silver ions and stabilizing nanoparticle formation. However, the optimal volume of NaOH has not been extensively investigated in apple peel-based synthesis systems. Therefore, this study not only focuses on green synthesis using apple peel extract but also systematically investigates the optimization and effect of NaOH volume on the formation, stability, and yield of silver nanoparticles.

By integrating sustainable chemistry, nanotechnology, and waste valorization, this work donates to the growing body of green nanoscience and highlights the need for further investigation of fruit waste in biomedical and environmental applications.

2. Materials and Methods

2.1 Materials

All apparatuses used in this study were of analytical mark. Silver nitrate ($AgNO_3$), sodium hydroxide (NaOH), and dimethyl sulfoxide (DMSO) were credited from Sigma-Aldrich. Deionized water was used all over the tests. Nutrient agar and Sabourose dextrose agar were gotten from HiMedia Laboratories for culturing bacteria and fungi, separately. The bacterial strains used were *Escherichia coli* (Gram-negative) and *Klebsiella pneumoniae* (Gram-negative), while the fungal strains included *Aspergillus flavus* and *Aspergillus niger*.

2.2 Collection and Preparation of Apple Peel Extract

Fresh red apples (*Malus domestica*) were bought from a local market in Bannu, Pakistan. The apples were cleaned carefully with distilled water and peeled. The peels were shade-dried for 15 days (took a bite longer time than normal because the weather was moister) at room temperature to avoid degradation of phytochemicals. Dehydrated peels were ground into a fine ash using electric grinder. To make the extract, 5 grams of the powder were boiled in 100 mL of deionized water for 10 minutes. The blend was filtered through Whatman No.1 filter paper and kept at 4°C until other use.

Figure 1: Schematic representation for the preparation of silver nanoparticles from Apple peel extract

2.3 Green Synthesis of Silver Nanoparticles

In deionized water, A 0.01 M silver nitrate solution was prepared. In a 25 mL beaker, 1 mL of $AgNO_3$ solution was mixed with 0.5 mL of apple peel extract and 0.5 mL of 0.1 M NaOH. With 8 mL of deionized water, the solution was dilute. The mixture was stirred uninterruptedly at room temperature for unchanging reaction. A color alteration from pale yellow to dark brown within 40–60 minutes confirmed the development of silver nanoparticles. The solution was left to stand for 24 hours at room temperature in the dim to complete the reduction process.

AgNPs **Color change from pale yellow to dark brown**

Figure 2: Synthesis and visual representation of silver nanoparticles

2.4 Optimization of NaOH Volume for AgNP Synthesis

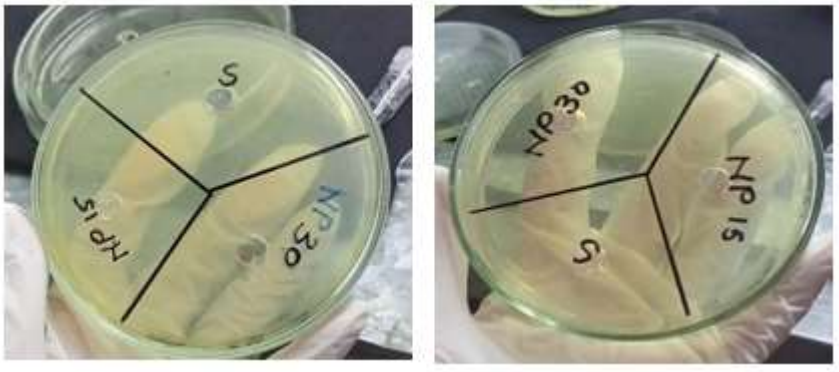
To determine the optimal concentration of NaOH for the synthesis of silver nanoparticles, a set of reaction mixtures were organized. Each mixture contained the same volume of 0.01 M silver nitrate (1 mL), apple peel extract (0.5 mL), and deionized water (8 mL), while the volume of NaOH was varied: 5 µL, 10 µL, 15 µL, 20 µL, 30 µL, 40 µL, 50 µL, 60 µL, 80 µL, and 100 µL. All models were stirred and incubated under ambient conditions. A color change was observed in all samples, signifying nanoparticle formation. UV–Visible spectra were then documented for each sample to monitor surface plasmon resonance and recognize the optimum NaOH volume.

Figure 3: Synthesis of Ag-NPs (at different NaOH concentration)

2.5 Antibacterial Assay

The antibacterial activity of AgNPs was measured using the agar well diffusion method. Nutrient agar plates were prepared and inoculated with *E. coli* and *K. pneumoniae* via sterile cotton swabs. Wells of 6 mm diameter were made and filled with two concentrations of AgNP solution: NP-30 (30 µL) and NP-15 (15 µL). DMSO was used as the solvent control, while erythromycin (10 wwwµg/disc) assisted as the

positive control. Plates were incubated at 37°C for 24 hours. The diameter of the inhibition zones was measured in millimeters using a Vernier caliper.



(a) E.coli cultured petri plate. (b) Klebsilia pneumonia cultured petri plate

Figure 4: Antibacterial activities of silver nanoparticles before result.

2.6 Antifungal Assay

Sabouraud dextrose agar (SDA) slants were set in sterile test tubes and inoculated with spores of

A. flavus and *A. niger*. Two sets were organized with NP-30 and NP-15 AgNP concentrations.

Controls included one tube without AgNPs and another treated with standard saffron antifungal agent. Tubes were incubated at 28°C and fungal growing was checked daily for 7 days. The fungal growth diameter was measured on day 3 and day 7 to evaluate the effectiveness of AgNPs.

(a) test tubes having standard saffron or +ive control **(b)** test tubes in which standard saffron were not added or –ive control **(c)** test tubes having nanoparticle concentration 30 or NP-30 **(d)** test tubes having nanoparticle concentration 15 or NP-15. (Letters F and N means Aspergillus flavous and Aspergillus nigras inoculated test tubes respectively)

Figure 5: Antifungal activity of synthesized silver nanoparticles;

3. Results and Discussion

3.1 Effect of NaOH Volume on AgNP Formation

The quantity of NaOH meaningfully influenced the synthesis of silver nanoparticles. An observable color change from yellow to dark brown or blue was observed, dependent on NaOH amount. UV–Visible spectroscopy exposed that the sample with 40 µL NaOH produced the most powerful and sharp surface plasmon resonance peak at 412 nm (Figure 10), representing optimal nanoparticle formation. This sample seemed dark blue, suggesting the formation of well-dispersed and stable AgNPs.

Lower concentrations (5–15 µL) presented weaker SPR peaks, suggesting inadequate reduction. Higher NaOH concentrations (above 50 µL) lead to broadening of the SPR peak, representing potential nanoparticle aggregation or heterogeneity.

NaOH boosts the reduction potential of the medium, accelerating the alteration of silver ions to nanoparticles. However, extreme alkalinity can destabilize the system, disturbing nanoparticle size and distribution. Therefore, an optimal NaOH concentration of 40 µL was established and used for preparing a 100 mL bulk AgNP solution for additional antimicrobial testing.

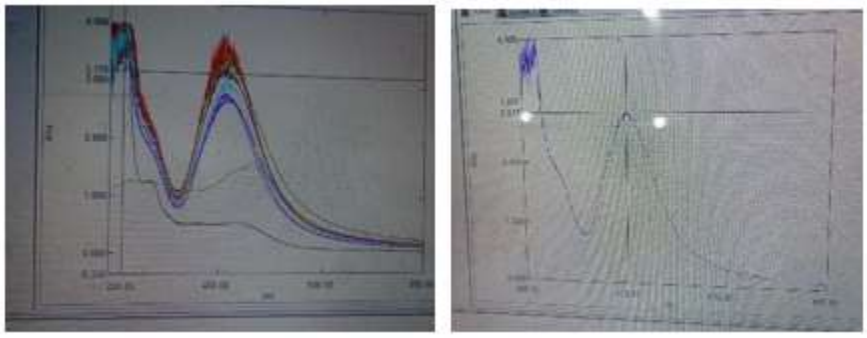


Figure 6: UV–Vis spectrum of synthesized AgNPs from Apple peels extract (at different NaOH concentration)

3.2 Antibacterial Activity

AgNPs presented concentration-dependent antibacterial activity. NP-30 verified inhibition zones of 2.0 cm for *K. pneumoniae* and 1.5 cm for *E. coli*, whereas NP-15 showed to some extent lower zones (1.5 cm and 1.2 cm, respectively). The positive control, erythromycin, presented a 3.0–3.1 cm zone. These results approve that apple peel-derived AgNPs are proficient of disrupting bacterial cell membranes. The mechanism likely includes penetration of the bacterial envelope, ROS generation, and interference with DNA replication and protein synthesis [1,3,6].

Inhibition against E.coli. inhibition against Klebsilia pneumonia.

Figure 8: Inhibition zone of bacteria

3.3 Antifungal Activity

On day 3, NP-30 treatment partial fungal growth to 5.0 cm in both A. flavus and A. niger, while NP-15 showed somewhat weaker inhibition (4.0 cm and 2.7 cm, respectively). By day 7, NP-30 tubes showed growth of 7.0 cm (*A. flavus*) and 6.0 cm (*A. niger*), whereas untreated controls touched the full tube length (10 cm). The antifungal mechanism is supposed to involve disruption of fungal hyphae and spore germination through oxidative stress and interaction with sulfur- containing proteins and phosphorous compounds.

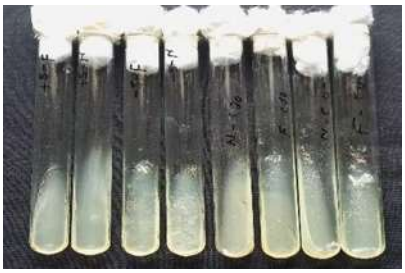


Figure 9: Inhibition against Aspergillus nigras and Aspergillus flavous

These results are consistent with literature on biosynthesized AgNPs from pomegranate, neem, and banana peels. The comparative antimicrobial efficacy shows that apple peels are equally powerful and offer an effective alternative for waste valorization and biomedicine.

4. Conclusion

This study reveals a simple, well-organized, and green method for synthesizing silver nanoparticles using apple peel extract. The process is low-cost, eco-friendly, and uses agricultural waste effectively. The synthesized AgNPs showed significant antimicrobial activity against both Gram-negative bacteria (*E. coli* and *K. pneumoniae*) and filamentous fungi (*A. flavus* and *A. niger*), with results strongly dependent on nanoparticle concentration.

The results align with earlier published work on pomegranate peel-based AgNPs, confirming that apple peels are a capable bioresource for nanoparticle synthesis. This adds a new measurement to fruit waste utilization, connecting sustainable chemistry with public health assistances.

Further studies are encouraged to characterize these nanoparticles via FTIR, SEM, and XRD, and to explore their cytotoxicity and applicability in vivo. Potential applications include antimicrobial coatings, water purification, medical textiles, and wound healing formulations.

Conflict of Interest

The author declares no conflict of interest.

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Author Contributions

Madina conducted the experiments, analyzed the data, and wrote the manuscript.

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