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Green Synthesis of Silver Nanoparticles Using Azadirachta indica Leaf Extract and Their Catalytic Activity in Methylene Blue Reduction

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Abstract — The present study investigates a green route for the synthesis of silver nanoparticles (AgNPs) using an aqueous leaf extract of Azadirachta indica (neem) and evaluates their catalytic activity in the reduction of methylene blue (MB) in aqueous medium. Fresh neem leaves were washed, chopped, boiled in double-distilled water, filtered, and used as the plant-mediated reducing and capping system. For nanoparticle synthesis, 75 mL of 1 mM silver nitrate solution was mixed with 5 mL of the leaf extract and subjected to microwave irradiation at 800 W and 2450 MHz for 300 s. Formation of AgNPs was indicated by the development of a yellowish-brown to brown colour and was monitored using UV–visible spectroscopy. An absorption band in the region of approximately 408–420 nm was observed and attributed to the surface plasmon resonance (SPR) of silver nanoparticles. The synthesized material was subsequently examined as a nanocatalyst for the NaBH4-assisted reduction of methylene blue. The progress of the reaction was monitored at 664 nm. The original project report indicates that complete reduction occurred within approximately 9 min under one catalyst condition and approximately 15 min when a lower AgNP concentration of 0.011 mg/mL was used, demonstrating that catalyst loading influenced the observed reaction rate. The findings support the usefulness of neem-mediated microwave synthesis as a rapid and comparatively environmentally benign route to AgNPs and indicate their potential for catalytic treatment of dye-containing aqueous systems. Because the original project did not report particle-size measurements, electron microscopy, magnetic characterization, kinetic constants, or statistical testing, these parameters are not inferred in the present article.

Keywords— silver nanoparticles, green synthesis, Azadirachta indica, neem, microwave irradiation, surface plasmon resonance, methylene blue, catalysis

I. INTRODUCTION

Nanotechnology concerns the design, synthesis, characterization, and application of materials with dimensions in the nanoscale regime. At this scale, materials may exhibit physicochemical properties that differ from those of their bulk counterparts because of their high surface-area-to-volume ratio and size-dependent electronic effects. Silver nanoparticles are particularly important because their optical, electrical, catalytic, and antimicrobial properties make them useful in diverse technological and environmental applications

Several physical and chemical routes are available for preparing silver nanoparticles, including evaporation–condensation, laser ablation, chemical reduction, electrochemical methods, radiolysis, and microwave-assisted processing. Although conventional methods can provide control over nanoparticle formation, some chemical routes require reducing or stabilizing agents that may create environmental or purification concerns. Biological and plant-mediated approaches have therefore received considerable attention as alternatives because plant extracts contain metabolites capable of reducing metal ions and stabilizing the resulting particles.

Green synthesis using plant material is attractive because the extraction process is comparatively simple and plant metabolites can perform more than one function in nanoparticle formation. Neem (Azadirachta indica), a widely available plant belonging to the family Meliaceae, is especially relevant because its leaves contain a variety of phytochemicals. Previous studies have demonstrated that aqueous neem extracts can mediate the formation of silver nanoparticles, with plant-derived compounds acting as reducing and capping agents.

Microwave irradiation offers an additional route for accelerating nanoparticle formation. The submitted project report describes a microwave-assisted synthesis in which an aqueous neem leaf extract was combined with 1 mM silver nitrate and irradiated for 300 s. The resulting material was characterized primarily through UV–visible spectroscopy. The report further examines the catalytic reduction of methylene blue by sodium borohydride in the presence of the synthesized AgNPs.

Methylene blue is a cationic dye with a strong visible absorption near 664 nm in its oxidized form. Its reduction to a colourless leuco form provides a convenient spectrophotometric model for examining catalytic electron-transfer reactions. Biosynthesized silver nanoparticles have previously been investigated as catalysts for the reduction of organic dyes by sodium borohydride.

Objectives

- To prepare an aqueous extract of Azadirachta indica leaves.
- To synthesize silver nanoparticles using the neem leaf extract under microwave irradiation.
- To monitor the formation of silver nanoparticles using UV–visible spectroscopy.
- To investigate the catalytic reduction of methylene blue using the synthesized silver nanoparticles and sodium borohydride.

II. REVIEW OF RELATED LITERATURE

Green synthesis of metal nanoparticles has developed as an important research area because biological materials can provide reducing, capping, and stabilizing functions. Song and Kim (2009) demonstrated that several plant leaf extracts could reduce Ag^+ to metallic silver and showed that synthesis rate and particle size could be influenced by reaction conditions. Their work illustrates the broader feasibility of plant-mediated nanoparticle production without relying exclusively on conventional chemical reducing agents.

Neem has subsequently been investigated specifically as a biological source for silver nanoparticle synthesis. Roy et al. (2017) reported green synthesis using Azadirachta indica leaf extract and attributed the reducing and capping activity to phytochemicals including flavonoids and terpenoids. Other work has also shown that aqueous neem extract can produce AgNPs with characteristic UV–visible absorption in the approximately 436–446 nm region, depending on experimental conditions (Elavazhagan & Arunachalam, 2011; Ibrahim, 2015). These studies indicate that the exact SPR position can vary with particle size, morphology, reaction conditions, and the chemical composition of the extract.

Microwave-assisted approaches have been explored because they can substantially shorten reaction time. In plant-mediated systems, rapid colour development and the appearance of a characteristic AgNP SPR band provide convenient preliminary evidence of nanoparticle formation. However, UV–visible spectroscopy alone does not provide complete structural characterization; complementary techniques such as X-ray diffraction, electron microscopy, dynamic light scattering, and infrared spectroscopy are normally required when particle size, crystallinity, morphology, and surface chemistry are central to the research question (Iravani et al., 2014).

The catalytic reduction of dyes using AgNPs is commonly interpreted through an electron-transfer mechanism. In the presence of sodium borohydride, the nanoparticle surface can facilitate transfer of electrons to adsorbed dye molecules, overcoming kinetic limitations associated with direct reduction. Vidhu and Philip (2014) demonstrated the usefulness of biosynthesized AgNPs in the catalytic degradation/reduction of several organic dyes, including methylene blue, and reported that catalytic performance could depend on nanoparticle characteristics.

III. MATERIALS AND METHODS

Materials

The project report lists silver nitrate, fresh Azadirachta indica leaves, methylene blue, sodium borohydride, and distilled/double-distilled water as the principal materials. UV–visible spectral measurements were performed using a UV-1800 spectrophotometer. Microwave irradiation was carried out using an IFB Solo 20PM1S domestic microwave oven operating at 800 W and 2450 MHz.

Preparation of Azadirachta indica Leaf Extract

Fresh green Azadirachta indica leaves were collected and washed thoroughly with running tap water followed by double-distilled water. The leaves were chopped into small pieces, and 5 g of leaf material was transferred to a round-bottom flask fitted with a water condenser. The material was boiled with 100 mL of double-distilled water for 10 min. After cooling, the extract was filtered through Whatman No. 1 filter paper and stored in airtight bottles under refrigerated conditions until use.

Microwave-Assisted Biosynthesis of Silver Nanoparticles

A 75-mL portion of 1 mM silver nitrate solution was placed in a 250-mL beaker, followed by addition of 5 mL of Azadirachta indica leaf extract. The mixture was stirred thoroughly and subjected to microwave irradiation at 800 W and 2450 MHz for 300 s. Formation of AgNPs was monitored by UV–visible spectroscopy. The project report describes a visible colour change from the initial colourless solution toward yellowish brown/brown following irradiation.

UV–Visible Characterization

The reaction mixture was examined using a UV-1800 UV–visible spectrophotometer. During nanoparticle formation, spectra were recorded in the 300–600 nm range, with measurements described at 20-s intervals from 120 s onward. The project report identifies an absorption feature around 408–420 nm as the SPR band of the silver nanoparticles. The increase in band intensity with reaction time was interpreted as evidence of progressive nanoparticle formation.

Catalytic Reduction of Methylene Blue

Catalytic activity was evaluated by monitoring the reduction of methylene blue by sodium borohydride in the presence of the synthesized AgNPs. In one experiment, 0.5 mL of freshly prepared 0.05 M $NaBH_4$ was added to 2 mL of aqueous methylene blue solution (0.08×10^{-3} M), followed by 0.5 mL of nanocatalyst solution. The reaction was monitored spectrophotometrically at 1-min intervals over 200–800 nm at ambient temperature, with particular attention to the 664-nm absorption maximum.

A second catalyst-loading condition was reported using 0.5 mL of AgNP solution at 0.011 mg/mL with 2.5 mL of 0.08 mM methylene blue and 0.5 mL of 0.05 M $NaBH_4$. The project report states that the lower AgNP concentration required approximately 15 min for complete disappearance of the methylene-blue absorption, compared with approximately 9 min under the higher-catalyst condition.

IV. RESULTS

Formation of Silver Nanoparticles

The addition of neem leaf extract to the silver nitrate solution followed by microwave irradiation resulted in a progressive colour change. The project report describes the reaction mixture as changing from colourless to yellowish brown/brown. Such colour development is consistent with the formation of colloidal silver nanoparticles and the appearance of their surface plasmon resonance. The rapid reaction under microwave irradiation is one of the notable features of the reported procedure.

UV–Visible Spectral Characteristics

The UV–visible spectra provided the principal characterization evidence in the project. An absorption peak was observed at approximately 408 nm during the reaction, while the final discussion identifies a band around 420 nm as the SPR feature of AgNPs. The intensity of the band increased with reaction time without a major change in its position. The project interprets the relatively symmetrical band as evidence consistent with a comparatively uniform and more-or-less spherical nanoparticle population.

The observed SPR region is broadly consistent with published reports on plant-mediated silver nanoparticles, although exact peak positions differ between studies because of differences in extract composition, silver-ion concentration, pH, irradiation, particle size, and morphology (Ibrahim, 2015; Roy et al., 2017). Thus, the present UV–visible result supports nanoparticle formation but should not be used alone to claim a precise particle-size distribution.

Catalytic Reduction of Methylene Blue

Methylene blue displayed a strong absorption feature at approximately 664 nm. After addition of sodium borohydride and AgNPs, the intensity of the 664-nm band decreased progressively with reaction time, accompanied by fading of the blue colour. The project report states that a new feature appeared near 290 nm and was associated with the formation of the reduced, colourless leuco form of methylene blue.

Under the higher catalyst condition described in the report, the reduction was completed in approximately 9 min. When the AgNP concentration was reduced to 0.011 mg/mL, approximately 15 min was required for complete reduction. The difference indicates that the amount of nanocatalyst affected the observed reaction rate. The project also reports that the reaction proceeded very slowly in the absence of the nanocatalyst, supporting the conclusion that AgNPs substantially accelerate the electron-transfer process.

Table 1: Experimental conditions and observations reported in the project

Stage	Condition	Observation
Leaf extract	5 g leaves + 100 mL double-distilled water; boiled 10 min	Filtered aqueous neem extract
AgNP synthesis	75 mL of 1 mM $AgNO_3$ + 5 mL extract; 800 W, 2450 MHz, 300 s	Yellowish-brown/brown colour develops
UV–Vis monitoring	300–600 nm; readings during irradiation	SPR feature approximately 408–420 nm
Catalytic test	MB + $NaBH_4$ + AgNPs; monitor at 664 nm	Progressive decrease in MB absorbance
Higher catalyst condition	Catalyst concentration higher than 0.011 mg/mL	Complete reduction reported in ~9 min
Lower catalyst condition	0.011 mg/mL AgNP solution	Complete reduction reported in ~15 min

V. DISCUSSION

The findings demonstrate a practical plant-mediated approach to silver nanoparticle synthesis using Azadirachta indica leaf extract. The procedure combines a simple aqueous extraction step with microwave irradiation and therefore avoids the need for a separate synthetic organic reducing agent during nanoparticle formation. This is consistent with the broader literature describing plant extracts as sources of biomolecules capable of reducing silver ions and stabilizing newly formed nanoparticles (Iravani et al., 2014; Song & Kim, 2009).

The observed colour change and UV–visible absorption band provide complementary visual and spectroscopic evidence of AgNP formation. Surface plasmon resonance occurs because conduction electrons associated with metallic nanoparticles interact collectively with incident electromagnetic radiation. Its position and shape are influenced by nanoparticle size, morphology, aggregation state, and the surrounding medium. The reported band around 408–420 nm therefore provides useful evidence for the presence of colloidal silver but does not, by itself, establish exact morphology or crystallite size.

The catalytic experiment further demonstrates the functional value of the synthesized material. Direct reduction of methylene blue by sodium borohydride is kinetically slow under the experimental conditions described in the project, whereas the presence of AgNPs markedly accelerates the process. A reasonable interpretation is that the nanoparticle surface acts as an electron-transfer mediator between borohydride-derived electrons and the adsorbed dye molecules. The large interfacial area of nanoscale silver provides an active surface for adsorption and electron transfer, thereby facilitating the conversion of coloured methylene blue to its reduced leuco form. Similar catalytic behaviour has been reported for biosynthesized silver nanoparticles in dye-reduction systems (Vidhu & Philip, 2014).

The difference between the two catalyst concentrations reported in the project is also important. Complete reduction was reported in about 9 min under the higher-catalyst condition and about 15 min when the catalyst concentration was 0.011 mg/mL. This trend suggests that increasing the available catalyst surface can enhance the apparent reaction rate. However, the original project does not provide a full concentration series, absorbance-versus-time dataset, rate constants, or a formal kinetic model. Consequently, the present article reports the observed time difference descriptively rather than calculating a quantitative catalytic rate law.

An important methodological consideration is the scope of characterization. The original report contains statements referring to X-ray diffraction and crystallinity in its conclusion, but the experimental characterization section explicitly describes UV–visible spectroscopy and does not provide an XRD dataset. For publication integrity, this article therefore does not claim independently verified crystallinity. Likewise, the original title describes the catalyst as 'magnetically separable,' but the project does not report magnetic measurements or a magnetic support. That descriptor has been removed from the present article title because it is not supported by the reported methods and results.

The study has practical relevance for environmentally oriented catalysis because dye-containing wastewater is a persistent concern in textile and related industries. Silver nanoparticle catalysis may provide a useful model system for rapid reduction of dye molecules. Nevertheless, practical wastewater treatment would require further work on catalyst recovery, silver leaching, reusability, toxicity, treatment of real industrial effluents, and process economics. These aspects were outside the scope of the submitted project and should be investigated before making application-level claims.

Limitations of the Study

- The project primarily used UV–visible spectroscopy for nanoparticle characterization; complementary SEM/TEM, XRD, FTIR, DLS, or elemental analyses were not reported in sufficient detail.
- A complete raw absorbance-versus-time dataset was not supplied, so formal kinetic constants and statistical uncertainty could not be calculated.
- Only limited catalyst concentrations were described, restricting quantitative optimization of catalyst loading.
- Magnetic separation was not experimentally demonstrated and therefore is not claimed in this article.
- The catalytic experiment used model methylene blue solutions rather than characterized real industrial wastewater.

VI. CONCLUSION

The study presents a simple and rapid green route for synthesizing silver nanoparticles using Azadirachta indica leaf extract under microwave irradiation. The aqueous neem extract functioned as the biological component of the synthesis, and the development of a characteristic UV–visible SPR band around 408–420 nm supported the formation of AgNPs. The synthesized nanoparticles demonstrated marked catalytic activity in the sodium-borohydride-assisted reduction of methylene blue, with faster reduction observed at the higher catalyst loading described in the project. The results indicate that neem-mediated AgNPs have potential as catalysts for model dye-reduction reactions. For stronger journal-level evidence, future studies should include rigorous particle characterization, replicate experiments, kinetic analysis, catalyst recovery and reuse studies, silver-leaching measurements, and testing with authentic dye-containing wastewater.

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