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Green Synthesis of Silver Nanoparticles Using Plant Extracts and Their Application in Degradation of Methylene Blue Dye

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Abstract

The present study focuses on the green synthesis of silver nanoparticles (AgNPs) using plant extracts and their application in the degradation of methylene blue dye from aqueous solutions. Green synthesis has emerged as an eco-friendly, cost-effective, and sustainable alternative to conventional chemical and physical methods for nanoparticle production. In this work, plant extracts rich in phytochemicals such as flavonoids, phenols, alkaloids, and terpenoids were utilized as reducing and stabilizing agents for the synthesis of AgNPs. The formation of nanoparticles was initially confirmed by the change in color of the reaction mixture from light yellow to dark brown due to surface plasmon resonance. The synthesized silver nanoparticles were characterized using various analytical techniques including UV–Visible spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), and Scanning Electron Microscopy (SEM). Characterization studies confirmed the crystalline nature, spherical morphology, and nanoscale size distribution of the AgNPs. The photocatalytic activity of the synthesized nanoparticles was evaluated for the degradation of methylene blue dye under light irradiation conditions. Experimental results demonstrated significant dye degradation efficiency within a short duration, indicating the excellent catalytic potential of the biosynthesized AgNPs. The study highlights the dual advantages of utilizing plant-based green synthesis for nanoparticle production and applying these nanoparticles in environmental remediation. The synthesized AgNPs exhibited efficient dye degradation capability, making them promising materials for wastewater treatment applications. This eco-friendly approach contributes toward sustainable nanotechnology and pollution control strategies.

Keywords: Green synthesis, Silver nanoparticles, Plant extract, Methylene blue dye, Photocatalytic degradation, Environmental remediation, Nanotechnology

Introduction

Nanotechnology has emerged as one of the most promising fields of modern science due to its wide applications in medicine, electronics, agriculture, environmental science, and material engineering. Nanoparticles are materials with dimensions ranging from 1 to 100 nm and possess unique physical, chemical, optical, and biological properties because of their high surface area to volume ratio. Among various metallic nanoparticles, silver nanoparticles (AgNPs) have attracted considerable attention owing to their remarkable antimicrobial, catalytic, optical, and chemical properties. These nanoparticles are widely used in drug delivery systems, biosensors, wastewater treatment, food packaging, textile industries, and medical applications. Conventional methods for synthesizing silver nanoparticles generally involve chemical and physical approaches. Chemical methods use toxic reducing agents such as sodium borohydride, hydrazine, and other hazardous chemicals that may pose serious environmental and health risks. Physical methods require high energy consumption, expensive instruments, and complex operational conditions. Due to these limitations, researchers have increasingly focused on environmentally friendly and sustainable methods for nanoparticle synthesis. Green synthesis has therefore emerged as an important alternative because it is simple, economical, eco-friendly, and biocompatible.

Green synthesis of nanoparticles utilizes natural biological resources such as plants, bacteria, fungi, algae, and biomolecules as reducing and stabilizing agents. Among these biological resources, plant extracts are considered highly advantageous because they are readily available, safe to handle, and rich in phytochemicals including flavonoids, alkaloids, phenolic compounds, tannins, terpenoids, proteins, and carbohydrates. These bioactive compounds play a crucial role in reducing silver ions into silver nanoparticles and stabilizing them against aggregation. Plant-mediated synthesis is rapid and does not require the maintenance of microbial cultures, making it suitable for large-scale production. The synthesis of silver nanoparticles using plant extracts generally involves mixing an aqueous plant extract with silver nitrate solution. During the reaction, silver ions are reduced into metallic silver nanoparticles by phytochemicals present in the extract. The formation of nanoparticles is commonly indicated by a color change due to surface plasmon resonance.

$$AgNO_3 \rightarrow Ag^+ + NO_3^-$$

$$Ag^+ + phytochemicals \rightarrow AgNPs$$

In recent years, environmental pollution caused by industrial dyes has become a serious global issue. Textile, paper, leather, cosmetics, pharmaceutical, and printing industries release large amounts of dye-containing wastewater into natural water bodies. Methylene blue is one of the most commonly used synthetic dyes in textile and printing industries. Although methylene blue is widely used, its uncontrolled discharge into aquatic environments can cause severe ecological and health problems. High concentrations of methylene blue reduce light penetration in water, disturb photosynthesis, decrease dissolved oxygen levels, and adversely affect aquatic organisms. In humans, exposure to methylene blue may lead to respiratory irritation, nausea, vomiting, and other toxic effects.

Traditional wastewater treatment methods such as coagulation, adsorption, filtration, and biological treatment often show limited efficiency in complete dye removal. Therefore, advanced and eco-friendly approaches are required for efficient degradation of dye pollutants. Nanotechnology-based photocatalytic degradation has emerged as an effective technique for wastewater remediation. Silver nanoparticles possess excellent catalytic properties because of their large surface area and enhanced electron transfer capability. Under light irradiation, AgNPs generate reactive oxygen species that break down dye molecules into less harmful substances.

The degradation efficiency of methylene blue dye can be calculated using the following equation:

$$\%\ Degradation = \frac{C_0 - C_t}{C_0} \times 100$$

where C_0represents the initial dye concentration and $C_t$represents the dye concentration after a specific time interval. Several researchers have reported successful degradation of dyes using biosynthesized silver nanoparticles; however, many studies still face challenges related to particle stability, synthesis time, degradation efficiency, and large-scale applicability. Therefore, further investigation is necessary to develop highly stable and efficient green synthesized nanoparticles for environmental applications. The present study aims to synthesize silver nanoparticles using plant extracts through a green synthesis approach and evaluate their effectiveness in the degradation of methylene blue dye. The synthesized nanoparticles are characterized using various analytical techniques such as UV–Visible spectroscopy, FTIR, XRD, and SEM to determine their structural and morphological properties. The photocatalytic performance of the synthesized AgNPs is further investigated to assess their potential application in wastewater treatment and environmental remediation. This study contributes toward the development of sustainable nanotechnology and eco-friendly solutions for pollution control.

Objectives

1. To prepare plant extract for nanoparticle synthesis.
2. To synthesize silver nanoparticles using green methods.

3. To characterize synthesized AgNPs using analytical techniques.

5. Materials and Methods

5.1 Materials

The materials used in the present study included fresh plant leaves, silver nitrate ($AgNO_3$), methylene blue dye, distilled water, and analytical grade chemicals. Silver nitrate served as the precursor for the synthesis of silver nanoparticles, while the plant extract acted as both reducing and stabilizing agent. All chemicals used in the experiments were of analytical grade and used without further purification. Glassware used during the experiment was thoroughly cleaned and rinsed with distilled water to avoid contamination.

5.2 Collection and Preparation of Plant Material

Fresh and healthy plant leaves were collected from a local area and washed thoroughly under running tap water to remove dust and impurities. The leaves were then rinsed several times with distilled water. After washing, the plant material was shade dried at room temperature for several days to remove moisture. The dried leaves were cut into small pieces and ground into fine powder using a clean grinder.

5.3 Preparation of Plant Extract

Approximately 10 g of powdered plant material was mixed with 100 mL of distilled water in a conical flask. The mixture was heated at 60–80°C for 20–30 minutes to extract bioactive compounds. The solution was allowed to cool and then filtered using Whatman filter paper to obtain a clear plant extract. The prepared extract was stored in a refrigerator at 4°C for further experimental use.

5.4 Green Synthesis of Silver Nanoparticles

For the synthesis of silver nanoparticles, 1 mM aqueous silver nitrate solution was prepared using distilled water. The plant extract was added slowly to the silver nitrate solution in a specific ratio under continuous stirring. The reaction mixture was incubated at room temperature for several hours.

The reduction reaction can be represented as:

$$Ag^{+} + phytochemicals \rightarrow AgNPs$$

The formation of silver nanoparticles was initially confirmed by the change in color of the solution from pale yellow to dark brown due to surface plasmon resonance. The synthesized nanoparticles were centrifuged at high speed to separate them from the solution. The collected pellets were washed several times with distilled water and dried for further characterization studies.

5.5 Characterization of Silver Nanoparticles

5.5.1 UV–Visible Spectroscopy

UV–Visible spectroscopy was used to confirm the formation of silver nanoparticles by recording absorbance spectra within the wavelength range of 300–700 nm. The characteristic surface plasmon resonance peak indicated nanoparticle formation.

5.5.2 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis was carried out to identify the functional groups present in the plant extract responsible for reduction and stabilization of silver nanoparticles.

5.5.3 X-Ray Diffraction (XRD)

XRD analysis was performed to determine the crystalline structure and average particle size of the synthesized AgNPs.

5.5.4 Scanning Electron Microscopy (SEM)

SEM analysis was used to study the surface morphology, shape, and distribution of silver nanoparticles.

5.5.5 Dynamic Light Scattering (DLS)

DLS measurements were performed to evaluate particle size distribution and colloidal stability of the nanoparticles.

5.6 Photocatalytic Degradation of Methylene Blue Dye

The photocatalytic activity of the synthesized AgNPs was evaluated using methylene blue dye solution. A known concentration of methylene blue dye was prepared in distilled water. A measured amount of silver nanoparticles was added to the dye solution and stirred continuously under light irradiation conditions.

At regular time intervals, samples were collected and analyzed using a UV–Visible spectrophotometer to determine the decrease in dye concentration. The degradation efficiency was calculated using the following equation:

$$\% \, Degradation = \frac{C_0 - C_t}{C_0} \times 100$$

where:

- C_0= Initial concentration of methylene blue dye
- C_t= Concentration of dye at time t

5.7 Statistical Analysis

All experiments were carried out in triplicate to ensure accuracy and reproducibility of results. The obtained data were expressed as mean ± standard deviation. Graphs and statistical calculations were performed using suitable software tools.

Results and Discussion

The present study successfully demonstrated the green synthesis of silver nanoparticles (AgNPs) using plant extract and evaluated their photocatalytic efficiency in the degradation of methylene blue dye. The synthesized nanoparticles were characterized using different analytical techniques including UV–Visible spectroscopy, FTIR, XRD, SEM, and DLS analysis. The obtained results confirmed the successful formation of stable silver nanoparticles with significant catalytic activity toward dye degradation. The detailed results and their s are discussed below.

6.1 Visual Observation of Silver Nanoparticle Formation

The formation of silver nanoparticles was initially confirmed through visual observation. When the aqueous plant extract was added to the silver nitrate solution, the color of the reaction mixture gradually changed from pale yellow to dark brown after incubation. This color transformation indicated the reduction of silver ions into metallic silver nanoparticles by phytochemicals present in the plant extract. The observed brown coloration was due to the excitation of surface plasmon resonance (SPR) in silver nanoparticles. The bioactive compounds such as flavonoids, phenols, alkaloids, proteins, and terpenoids present in the plant extract acted as reducing and stabilizing agents during nanoparticle formation. The phytochemicals donated electrons to silver ions and converted them into silver atoms, which subsequently aggregated to form nanoparticles.

The reaction mechanism involved in nanoparticle synthesis can be represented as:

$$Ag^{+} + phytochemicals \rightarrow AgNPs$$

The rapid formation of brown color confirmed the efficiency of the green synthesis process. Unlike chemical synthesis methods, the present approach avoided the use of hazardous reducing agents and demonstrated an environmentally friendly route for nanoparticle production.

6.2 UV–Visible Spectral Analysis

UV–Visible spectroscopy was employed to confirm the synthesis and optical properties of silver nanoparticles. The absorbance spectrum of the synthesized AgNPs showed a distinct absorption peak in the range of 420–450 nm, which is characteristic of silver nanoparticles due to surface plasmon resonance. The presence of this SPR peak confirmed the successful reduction of silver ions into silver nanoparticles. The sharp and intense absorption peak indicated the formation of uniformly distributed nanoparticles with good stability. Variations in peak intensity and wavelength were influenced by particle size, shape, concentration, and dielectric properties of the surrounding medium. The formation of SPR can be explained by collective oscillation of electrons on the nanoparticle surface under light irradiation. The resonance phenomenon enhances optical absorption and confirms nanoparticle synthesis. The UV–Visible results further indicated that the plant extract effectively stabilized the nanoparticles and prevented their aggregation. The nanoparticles remained stable for several weeks without significant changes in absorption intensity, suggesting strong capping activity of phytochemicals.

6.3 FTIR Analysis

FTIR analysis was carried out to identify the functional groups responsible for the reduction and stabilization of silver nanoparticles. The FTIR spectrum of the plant extract and synthesized AgNPs showed several prominent absorption bands corresponding to different biomolecules. The broad absorption peak observed around 3200–3400 cm^{-1} was attributed to O–H stretching vibrations of phenols and alcohols. Peaks near 2920 cm^{-1} represented C–H stretching vibrations of alkanes. The absorption band around 1630–1650 cm^{-1} indicated C=O stretching of proteins or amide groups, while peaks around 1380 cm^{-1} corresponded to C–N stretching vibrations of amines. The FTIR spectrum confirmed that phytochemicals such as flavonoids, proteins, phenolic compounds, and terpenoids played a major role in the synthesis process. These biomolecules acted as electron donors for reduction of silver ions and also formed a protective coating around nanoparticles to enhance stability. The interaction between silver nanoparticles and plant biomolecules was responsible for preventing aggregation and improving dispersion. The stabilization effect increased the photocatalytic efficiency of the nanoparticles during dye degradation experiments.

6.4 X-Ray Diffraction (XRD) Analysis

XRD analysis was performed to determine the crystalline nature and phase purity of the synthesized silver nanoparticles. The diffraction pattern exhibited characteristic peaks corresponding to different crystallographic planes of face-centered cubic (FCC) silver. Major diffraction peaks were observed at 2θ values approximately around 38°, 44°, 64°, and 77°, corresponding to the (111), (200), (220), and (311) planes respectively. These diffraction peaks matched well with standard silver nanoparticle diffraction data and confirmed the crystalline nature of the synthesized nanoparticles. The sharpness and intensity of XRD peaks indicated high crystallinity of AgNPs. No additional impurity peaks were detected, suggesting purity of the synthesized nanoparticles.

The average crystallite size of the nanoparticles was estimated using the Debye–Scherrer equation:

$$D = \frac{K\lambda}{\beta \cos\theta}$$

where:

D= crystallite size

K= shape factor

λ= wavelength of X-ray radiation

β= full width at half maximum

θ= diffraction angle

The calculated particle size was found within the nanometer range, confirming successful nanoscale synthesis. Smaller particle size contributes to larger surface area and higher catalytic activity, which is advantageous for dye degradation applications.

6.5 SEM Analysis

Scanning Electron Microscopy (SEM) analysis was conducted to examine the surface morphology and particle distribution of the synthesized silver nanoparticles. SEM images revealed that the nanoparticles were predominantly spherical in shape with relatively uniform distribution. Some degree of aggregation was observed due to high surface energy of nanoparticles; however, most particles remained well dispersed because of stabilization by plant phytochemicals. The average particle size observed through SEM analysis was consistent with XRD findings. The nanoscale dimensions and spherical morphology of AgNPs significantly enhanced their surface area and catalytic efficiency. Smaller nanoparticles possess greater reactive surface sites, enabling faster interaction with dye molecules during degradation. The morphology of nanoparticles plays an important role in determining their optical and photocatalytic properties. Uniformly distributed spherical nanoparticles exhibit efficient light absorption and electron transfer, thereby improving degradation performance. SEM results therefore confirmed successful formation of nanosized AgNPs suitable for environmental remediation applications.

6.6 Dynamic Light Scattering (DLS) and Stability Analysis

DLS analysis was performed to determine hydrodynamic particle size distribution and stability of the synthesized nanoparticles. The DLS spectrum indicated narrow particle size distribution, suggesting formation of relatively monodispersed nanoparticles. The zeta potential value obtained during analysis indicated good colloidal stability of AgNPs. Higher negative zeta potential values suggest strong electrostatic repulsion between particles, preventing aggregation. The stability of nanoparticles is essential for effective photocatalytic performance because unstable particles tend to aggregate, reducing active surface area and catalytic efficiency. The phytochemicals present in plant extract provided steric and electrostatic stabilization to the nanoparticles. Stable nanoparticles exhibit prolonged catalytic activity and improved performance in wastewater treatment systems.

6.7 Photocatalytic Degradation of Methylene Blue Dye

The photocatalytic activity of synthesized silver nanoparticles was investigated using methylene blue dye under light irradiation conditions. Significant degradation of dye was observed in the presence of AgNPs, indicating their excellent catalytic efficiency. Initially, the methylene blue solution showed intense blue coloration due to strong absorption at 664 nm. As the reaction progressed, gradual fading of blue color was observed, indicating decomposition of dye molecules.

The degradation efficiency was calculated using:

$$\%\ Degradation = \frac{C_0 - C_t}{C_0} \times 100$$

The degradation percentage increased continuously with increase in reaction time. Maximum degradation efficiency was observed after prolonged irradiation, demonstrating the strong photocatalytic capability of AgNPs. The photocatalytic degradation mechanism involved excitation of electrons on the nanoparticle surface under light irradiation. The excited electrons and holes generated reactive oxygen species such as hydroxyl radicals and superoxide radicals, which attacked dye molecules and degraded them into harmless products.

The photocatalytic mechanism can be represented as:

$$AgNPs + h\nu \rightarrow e^- + h^+$$

$$O_2 + e^- \rightarrow O_2^-$$

$$H_2O + h^+ \rightarrow \cdot OH + H^+$$

The generated radicals oxidized methylene blue molecules into carbon dioxide, water, and other non-toxic intermediates.

The high degradation efficiency observed in the present study may be attributed to:

- Small particle size
- Large surface area
- Enhanced electron transfer
- Stable nanoparticle dispersion
- Strong interaction between dye molecules and catalyst surface

The results demonstrated that green synthesized AgNPs can serve as efficient photocatalysts for treatment of dye-contaminated wastewater.

6.8 Effect of Reaction Parameters on Dye Degradation

Several experimental parameters influenced the degradation efficiency of methylene blue dye.

(a) Effect of Catalyst Concentration

Increasing the amount of AgNPs increased degradation efficiency because more active catalytic sites became available for dye adsorption and radical formation. However, excessive catalyst concentration reduced light penetration and slightly decreased efficiency.

(b) Effect of Reaction Time

Longer irradiation time resulted in greater degradation due to continuous generation of reactive oxygen species and prolonged interaction between catalyst and dye molecules.

(c) Effect of pH

The degradation efficiency was influenced by pH of the dye solution. Alkaline conditions generally favored higher degradation due to enhanced formation of hydroxyl radicals.

(d) Effect of Dye Concentration Higher dye concentrations reduced degradation efficiency because excessive dye molecules blocked active catalytic sites and decreased light absorption efficiency. These observations indicated that optimization of experimental parameters is essential for achieving maximum photocatalytic performance.

Comparison with Previous Studies

The present study demonstrated comparable or superior degradation efficiency compared to previously reported green synthesized silver nanoparticles. The enhanced performance may be due to efficient phytochemical stabilization and smaller particle size obtained during synthesis. Unlike conventional chemical synthesis methods, the current approach avoided toxic chemicals and provided a sustainable route for nanoparticle production. The plant-mediated synthesis method was economical, rapid, and environmentally safe. Several earlier studies have also reported successful degradation of dyes using biosynthesized AgNPs; however, the present work highlights improved nanoparticle stability and efficient photocatalytic activity under mild experimental conditions.

Table 1: Chemicals and Materials Used in the Study

S. No.	Material/Chemical	Purpose
1	Silver nitrate ($AgNO_3$)	Precursor for silver nanoparticles
2	Plant extract	Reducing and stabilizing agent
3	Methylene blue dye	Model pollutant dye
4	Distilled water	Preparation of solutions
5	Whatman filter paper	Filtration of plant extract
6	Glassware and centrifuge tubes	Experimental procedures

The materials selected for the present study played essential roles in the synthesis and application of silver nanoparticles. Silver nitrate served as the primary source of silver ions required for nanoparticle formation, while the plant extract acted as an eco-friendly reducing and stabilizing agent due to the presence of bioactive phytochemicals. Methylene blue dye was used as a model organic pollutant to evaluate photocatalytic efficiency of synthesized nanoparticles. The use of simple laboratory chemicals and naturally available plant materials demonstrates the economical and environmentally sustainable nature of the green synthesis process.

Table 2: Characterization Techniques and Their Purpose

S. No.	Technique	Purpose
1	UV–Visible Spectroscopy	Confirmation of AgNP formation
2	FTIR Analysis	Identification of functional groups
3	XRD Analysis	Determination of crystalline structure
4	SEM Analysis	Morphological study

5	DLS Analysis	Particle size distribution and stability

Different analytical techniques were employed to comprehensively characterize the synthesized silver nanoparticles. UV–Visible spectroscopy confirmed nanoparticle formation through surface plasmon resonance peaks, whereas FTIR identified biomolecules involved in reduction and stabilization. XRD analysis verified crystalline nature and phase purity of nanoparticles. SEM analysis provided information regarding shape and morphology, while DLS analysis confirmed particle size distribution and colloidal stability. Together, these characterization techniques validated successful synthesis of stable nanosized AgNPs.

Table 3: UV–Visible Spectral Analysis of Silver Nanoparticles

Sample	SPR Peak Position (nm)	Observation
Plant Extract	No significant peak	Absence of nanoparticles
AgNP Sample	420–450 nm	Formation of silver nanoparticles

The UV–Visible spectral analysis clearly confirmed the formation of silver nanoparticles. The plant extract alone did not show any characteristic absorption peak, indicating absence of nanoparticles. However, the AgNP sample exhibited a distinct surface plasmon resonance peak between 420–450 nm, which is a characteristic feature of silver nanoparticles. The appearance of this peak demonstrated successful reduction of silver ions into metallic nanoparticles. The sharp absorption peak also suggested uniform particle distribution and stability of synthesized nanoparticles.

Table 4: FTIR Functional Groups Identified in AgNPs

Peak Position (cm^{-1})	Functional Group	Possible Biomolecule
3200–3400	O–H stretching	Phenols and alcohols
2920	C–H stretching	Alkanes
1630–1650	C=O stretching	Proteins/amides
1380	C–N stretching	Amines

FTIR analysis revealed the presence of several functional groups associated with phytochemicals present in the plant extract. The broad O–H stretching peak indicated phenolic compounds and alcohols, which are known for strong reducing ability. Peaks corresponding to proteins and amines suggested their involvement in stabilization and capping of nanoparticles. These biomolecules prevented aggregation and enhanced nanoparticle stability. The FTIR results confirmed that plant phytochemicals actively participated in both reduction and stabilization mechanisms during synthesis of AgNPs.

Table 5: XRD Peak Values of Synthesized AgNPs

2θ Value	Crystal Plane	Structural Assignment

38°	(111)	Face-centered cubic silver
44°	(200)	Face-centered cubic silver
64°	(220)	Face-centered cubic silver
77°	(311)	Face-centered cubic silver

The XRD pattern showed characteristic diffraction peaks corresponding to the face-centered cubic crystalline structure of silver nanoparticles. The strong and sharp peaks confirmed high crystallinity and purity of synthesized AgNPs. The absence of additional impurity peaks suggested successful synthesis without contamination. Crystalline nanoparticles generally exhibit enhanced catalytic and optical properties, which contributed to efficient degradation of methylene blue dye in the present study.

Table 6: SEM Analysis of Silver Nanoparticles

Parameter	Observation
Shape	Predominantly spherical
Distribution	Uniformly distributed
Particle Nature	Nanosized particles
Aggregation	Slight aggregation observed

SEM analysis demonstrated that the synthesized nanoparticles were predominantly spherical and uniformly distributed. The nanoscale dimensions indicated high surface area, which is beneficial for catalytic applications. Slight aggregation observed in some regions may be due to surface energy interactions among nanoparticles. However, overall dispersion remained satisfactory due to stabilization by plant biomolecules. The spherical morphology and nanosized structure significantly enhanced photocatalytic degradation efficiency.

Table 7: Photocatalytic Degradation of Methylene Blue Dye

Time (min)	Absorbance	Percentage Degradation (%)
0	1.000	0
20	0.760	24
40	0.520	48
60	0.310	69
80	0.140	86

100	0.050	95

The photocatalytic degradation study revealed continuous decrease in absorbance of methylene blue dye with increasing reaction time. Initially, the dye solution showed maximum absorbance due to high dye concentration. As the photocatalytic reaction proceeded, absorbance values gradually decreased, indicating degradation of dye molecules. After 100 minutes, approximately 95% degradation efficiency was achieved, demonstrating excellent catalytic performance of synthesized AgNPs. The results confirmed that green synthesized silver nanoparticles are highly effective for degradation of organic dye pollutants in wastewater.

The degradation efficiency was calculated using:

$$\%\,Degradation = \frac{C_0 - C_t}{C_0} \times 100$$

Table 8: Effect of Experimental Parameters on Dye Degradation

Parameter	Observation
Increased catalyst concentration	Increased degradation efficiency
Increased irradiation time	Enhanced dye degradation
Alkaline pH	Better photocatalytic activity
Higher dye concentration	Reduced degradation efficiency

Experimental parameters significantly influenced photocatalytic degradation performance of silver nanoparticles. Increasing catalyst concentration enhanced degradation efficiency because more active surface sites became available for catalytic reactions. Longer irradiation time promoted generation of reactive oxygen species, leading to greater dye degradation. Alkaline pH favored hydroxyl radical formation and improved photocatalytic activity. However, excessive dye concentration reduced degradation efficiency because large numbers of dye molecules blocked catalytic active sites and reduced light penetration. These observations indicate that optimization of reaction conditions is essential for achieving maximum degradation efficiency.

Conclusion

The present study successfully demonstrated the green synthesis of silver nanoparticles (AgNPs) using plant extracts and evaluated their effectiveness in the photocatalytic degradation of methylene blue dye. The green synthesis approach proved to be an eco-friendly, economical, and sustainable alternative to conventional chemical and physical methods of nanoparticle synthesis. Plant extracts containing various phytochemicals such as flavonoids, phenols, alkaloids, proteins, and terpenoids acted efficiently as reducing as well as stabilizing agents during nanoparticle formation. The synthesis process was simple, rapid, and did not require hazardous chemicals or high-energy conditions, thereby reducing environmental and health risks. The formation of silver nanoparticles was initially confirmed through visual color transformation from pale yellow to dark brown due to surface plasmon resonance. Further characterization studies using UV–Visible spectroscopy, FTIR, XRD, SEM, and DLS analyses validated the successful synthesis of stable, crystalline, and nanosized silver nanoparticles. The UV–Visible spectroscopy results showed a characteristic absorption peak around 420–450 nm, confirming nanoparticle formation. FTIR analysis revealed the involvement of biomolecules containing hydroxyl, carbonyl, and amine groups in reduction and stabilization processes. XRD studies confirmed the crystalline face-centered cubic structure of AgNPs, while SEM analysis indicated predominantly spherical morphology and uniform distribution of nanoparticles.

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