Eco-friendly synthesis of silver nanoparticles using dry ginger rhizome extract and exploration of their photocatalytic performance

Sujana Acharya[*] and Kamal Prasad Sapkota[**]

[*]Department of Chemistry, Amrit Campus, Tribhuvan University, Kathmandu, Nepal.

[**]Central Department of Chemistry, Tribhuvan University, Kirtipur, Kathmandu, Nepal.

Abstract: Current study presents the synthesis of silver nanoparticles (Ag NPs) from a silver precursor utilizing the eco-friendly and cost-effective green synthesis method and their excellent photocatalytic performance. Initially, ginger rhizome powder extract was employed for the synthesis of silver nanoparticles from aqueous silver nitrate (precursor). Ginger rhizome extract was employed as a source of very useful phytochemicals. The extracted phytochemicals can act as capping and reducing agents. The characterization of the as-prepared Ag NPs was accomplished using different tools and techniques such as ultraviolet-visible (UV-Vis) spectroscopy, Fourier Transform infrared (FTIR) spectroscopy, X-ray diffractometry (XRD), field emission scanning electron microscopy (FE-SEM), high resolution transmission electron microscopy (HR-TEM), and energy-dispersive X-ray spectroscopy (EDS). UV-Vis spectra confirmed the formation of Ag NPs through the generation of absorbance peak at 425 nm, whereas FTIR analysis was effective to identify the biomolecules responsible for the reduction of silver ions into Ag NPs. XRD analysis confirmed the presence of crystalline structure of as-synthesized Ag NPs. Likewise, FE-SEM and HR-TEM accessed the shape, size, and morphology of nanoparticles. The as-synthesized nanoparticles were explored for their photocatalytic performance. Effective synthesis method and remarkable photocatalytic performance of the as-synthesized nanoparticles have revealed that they can be employed in the field of environmental detoxification as the sustainable remedy to water pollution because of organic dyes.

Keywords: Ag NPs; Green synthesis; Methylene blue; Photocatalytic activity; Reducing agents.

Introduction

Metal and metal oxide nanoparticles show characteristics features such as high dispersion in solid, high surface to volume ratio, antimicrobial properties, and photocatalysis[1]. Among different metals, silver nanoparticles are at the forefront of research because of their diverse industrial and pharmaceutical applications such as antimicrobial, catalysis, optical sensing and imaging applications[2]. Silver nanoparticles are generally synthesized from several methods including physical, chemical and biological methods. Physical and chemical methods are less effective and have more limitations in comparison with biological entities. The unique physical, chemical and biological properties are shown by nanoparticles due to their shape, size and morphology[3]. In a physical method, nanoparticles are synthesized using ceramic heater which is further used to evaporate the source materials. Since this method requires larger space area and large amount of energy, it is more time consuming for thermal stability and is more power consuming. Different approaches are involved in physical methods which include: evaporation, condensation and laser ablation. Physical method follows top-down approach in which bulk materials split into small sized nanoparticles[4]. Chemical method is used as conventional

Author of correspondence: Kamal Prasad Sapkota, Central Department of Chemistry, Tribhuvan University, Kirtipur, Kathmandu, Nepal.
Email: mychemistry2037@gmail.com / kamal.sapkota@cdc.tu.edu.np; https://orcid.org/0000-0002-0452-7796
Received: 23 April, 2026; Received in revised form: 12 May, 2026; Accepted: 19 May, 2026.
Doi: https://doi.org/10.3126/sw.v19i19.95717

method for the synthesis of nanoparticles. Silver nanoparticles can be synthesized when silver ions receive electrons from the reducing agent. Thus-formed nanoparticles are generally available in spherical shape[5].

Silver nitrate is the most commonly used chemical precursor during the chemical synthesis of silver nanoparticles. Other different chemicals are used to monitor the formation of nanoparticles; hydrazine hydrate is used as a reducing agent, ethylene glycol as a solvent as well as reducing agent, polyvinyl pyrrolidone (PVP) as a capping as well as size controlling agent and polyvinyl alcohol as stabilizing agent[6]. Different chemicals and reducing agents used during synthesis procedure are expensive, highly toxic, high-energy requirements and difficulty in waste purification[7].

Biological method uses green synthesis protocol for the synthesis of metal nanoparticles. Bacteria, yeast, fungi and plant species are used in biological methods and have various medical applications[5]. Plant sources are given higher priority as their different parts such as rhizome, leaf, flower and stem constitute different phytochemicals including alkaloids, flavonoids, saponins, and tannins which act as strong antioxidants, capping and stabilizing agents during the synthesis of nanoparticles[8]. Nanoparticles synthesized through green synthetic route are less toxic, eco-friendly in nature, less time consuming, economic and reliable in comparison with physical and chemical methods[9].

Green synthesis route is a natural, biocompatible and safer route that uses non-toxic chemicals in the synthesis protocol of silver nanoparticles with the utilization of lesser energy. For the synthesis of metal nanoparticles, through green synthesis method, plant species are chosen based on their availability and presence of their effective phytochemical constituents during the extract preparation. These biological components are responsible for the reduction of metallic salt into their respective metallic nanoparticles[10]. The main benefits of utilizing the plant extract in the production of silver nanoparticles are low synthesis rate, limited number of shape and size distribution, less wastage production, health and environment shielding, provision of healthy and hygienic environment and stable products[11].

Different vegetative parts of the plants such as leaves, root, flower and stem are generally used for the preparation of plant extract which is considered as the good source of capping and reducing agents. The selection of suitable plant materials for a successful synthesis of nanoparticles is a challenging work during research[9]. Different types of proteins, amino acids, enzymes and flavonoids are present in plant extracts which enhance the biosynthesis process. In addition, biomolecules present in plant extracts are environmentally benign, although they may be chemical complexes[10]. Dried ginger rhizome extract contains different phytochemical constituents, they are gingerol, zingerone, resin and starch. Gingerols are the chief useful compounds found in the rhizome of zinger[12].

Silver nanoparticles show strong inhibitory effect on microbes so, they have been used as excellent antimicrobial and anti-oxidant agents. This is due to variability in showing different unique properties such as catalysis, strong bactericidal and inhibitory effect[3]. Collective excitation of free electron gas from such metals results strong absorption in the visible region which results in increased study of metal nanoparticles[1]. Due to the presence of surface plasmon resonance (SPR) effect in nanoparticles, nanoparticles show their efficiency in showing wider application areas. Ag NPs are commonly used in different nanotechnological fields of research including molecular sensing, agriculture, solar cells, drug delivery system, DNA technology, nano sensor, food industry, anti-microbial property and optical property. The definite shape and size of nanoparticles is based on their optical property which shows their uniqueness in showing diverse application areas[3].

The main focus of our research work is to emphasize the use of organic components from the rhizome of ginger to synthesize the silver nanoparticles by following green synthesis method. The method also encompasses the extracting, measuring, handling and identifying different bio-active components available in rhizome of ginger plant. Typically, Ag NPs were prepared by using silver nitrate as silver precursor and aqueous ginger rhizome powder extract

as reducing as well as stabilizing agent. The as-synthesized silver nanoparticles were filtered to remove the remnant precursor molecules, plant extract and other unwanted liquids. The nanoparticles were then washed with distilled water many times and finally oven-dried to get the pure and dry nanoparticles. Thus-obtained silver nanoparticles were stored in a vial and tightly stoppered.

Materials and method

Sample collection and experimental site

Rhizome of ginger plant was collected from the local market. The sample was collected on the basis of easier availability, cost effectiveness and medicinal property.

All the research works related with the synthesis of silver nanoparticles using ginger rhizome plant extract was completed in Chemistry Research Laboratory of Amrit Campus, Tribhuvan University. UV-visible characterization (Labtronics Model LT - 2802) and FT-IR spectroscopic characterization (FTIR, TRACER-100) were carried out in the same Research Laboratory. Similarly, FE SEM (FE-SEM, SUB 8230, Hitachi, Chiyoda-ku, Tokyo, Japan), HR TEM (HR-TEM, JEM-2200FS, JEOL, Akishima, Tokyo, Japan) and XRD (XRD, Rigaku Smart Lab) characterization were done abroad. Likewise, photocatalysis and phytochemical screening were completed successfully in science laboratory of Amrit Campus.

Experimental Methods

Preparation of ginger rhizome extract

Fresh and healthy ginger rhizome was taken from local market and rinsed thoroughly to remove the adhering mud particle with the help of distilled water. After complete removal of peel and mud particles, rhizome of ginger was cut into small pieces and dried under sunlight for a week.

After complete drying, small pieces of ginger rhizome were ground into powdered form which is used for further studies. For the preparation of plant extract, 17 g of organic ginger rhizome powder was weighed and mixed with 200 mL of distilled water. Then, the mixture of solutions was boiled for 30 minutes. After cooling the solution, the filtration process was completed using Whatman filter paper. The filtered and clean extract was stored in an air-tight bottle and was employed to synthesize silver nanoparticles.

Preparation of silver nitrate solution

For the preparation of silver nitrate solution, 1.69 g of $AgNO_3$ crystal was dissolved in 100 mL of distilled water (0.10 M) and the stock solution was thus prepared.

Green synthesis of silver nanoparticles

By following the procedure of green synthesis, the extraction process is completed with some modification. For the preparation of silver nanoparticles, freshly prepared 10 mL of ginger rhizome plant extract was added to 50 mL of 0.1 M $AgNO_3$ solution in a 250 mL conical flask. The Ag^+ ions get reduced at normal room temperature (20°-30°C) under moderate stirring of the mixture solution with magnetic stirrer for 1 hour.

After stirring the mixture for an hour, initial light-yellow colour of plant extract solution was transformed into dark reddish-brown colour. This change in colour indicates the completion of the extraction process along with the formation of silver nanoparticles[14].

Thus-obtained brown colour suspension was then centrifuged at 2500 rpm for 10 minutes. The residue obtained after centrifugation was washed thoroughly with distilled water and ethanol repeatedly to remove the impurities and then dried to obtain the Ag NPs in solid form. The condition of sterility was maintained in every step and procedure for accuracy and effectiveness in result following the protocol reported elsewhere[3].

Preparation of plant extract for phytochemical screening

For phytochemical screening, dry ginger rhizome powder was collected. Then, 15 g of dry rhizome powder was mixed with 150 mL of distilled water and kept in a water bath at 85 °C for 30 min and was allowed to cool down. Thus-obtained aqueous extract was filtered and was further used for phytochemical tests.

Results and Discussions

Visual observation

A distinct colour formation, i.e., brown colour provided the preliminary indication of successful synthesis of nanoparticles. Here, the initial transparent yellow colour of plant extract solution was changed into brown colour after the addition of 0.1 M of $AgNO_3$ solution. There is change in colour of the solution with increment in time after continuous stirring of magnetic stirrer for an hour at room temperature (20 °C). Finally, ginger rhizome is capable of reducing silver nitrate solution and forming silver nanoparticles by following green synthesis method.

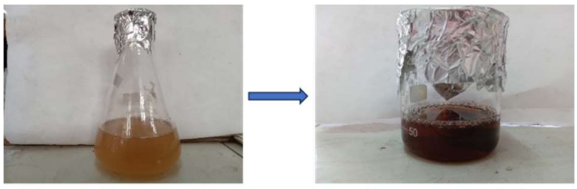


Figure 1: Colour change observation during synthesis of Ag NPs.

UV-Vis spectroscopic studies

The first step for the characterization of nanoparticles was the passing of UV-radiation through the sample which resulted in the generation of several peaks that appeared progressively in the range of 200 – 800 nm in the spectra.

The reduction of silver ions into Ag NPs was confirmed by the appearance of a characteristic peak in the UV-Vis spectra while observing spectra in the range of 200 to 800 nm. The optical properties of silver nanoparticles were studied thoroughly with the help of UV-Vis spectra. Absorption spectra were measured in the range of 200-800 nm, which provided information about the formation of silver nanoparticles. The absorption peak obtained at 425 nm in the UV-Vis absorption spectra of Ag NPs is assigned to the characteristic surface plasmon resonance (SPR) of the nanoparticles[13].

Different polyphenolic and phytochemical compounds were available in the ginger rhizome extract which are responsible for the reduction of Ag^+ ions during the synthesis of silver nanoparticles. Different phytochemical constituents such as alkaloid, flavonoid and phenolic groups act as stabilizing and reducing agents and supports the synthesis process[12]. As a result, green synthesized nanoparticles were obtained with the reduction of Ag^+ ions into Ag (0) when silver nitrate solution get mixed with ginger rhizome extract at given room temperature.

$$Ag^+_{(aq)} + \text{Ginger} \xrightarrow{\text{Stirring at 20}-\ ^\circ\text{C}} [\text{Ag (Ginger)}] \quad \ldots\ldots\ldots\ldots\ (1)$$

$$\text{Ag (ginger)} + \text{R-CHO} \xrightarrow{\text{Stirring at 20}-30^\circ\text{C}} [Ag^+ \text{ions}] \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

During the course of reaction, the aldehyde group present in the reducing sugar of rhizome extract is oxidized to carboxylic group. The electrons released due to the oxidation of aldehyde group are available for the reduction of Ag^+ ions into metallic nanoparticles[9].

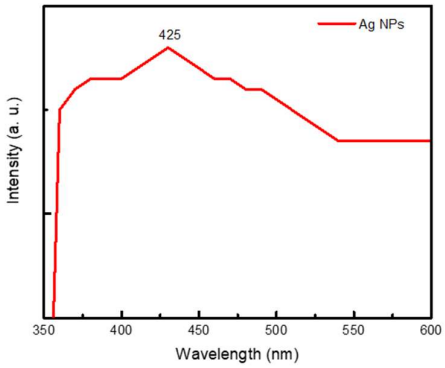


Figure 2: UV-vis spectra of Ag NPs with the peak value at 425 nm.

The result obtained from UV-Vis spectra was found to be consistent with the value reported in the literature[14]. Moreover, the result was also in accordance with the absorption peak at 425 nm when Ag NPs were synthesized using *Desmodium triflorum* extract[15].

Field Emission Scanning Electron Microscopy (FE-SEM) Studies

FE-SEM acts as the surface imaging characterization tool, which determines the shape, morphology and size distribution of nanoparticles under low magnification. Under different magnifications, surface morphology of nanoparticles was studied thoroughly. Information related to purity as well as aggregation of nanoparticles was obtained the FE-SEM technique. The morphological character was studied up to certain range but, study of the detailed internal structure of nanoparticles was not

satisfactory, and therefore, were studied further through high resolution transmission electron microscopy (HR-TEM).

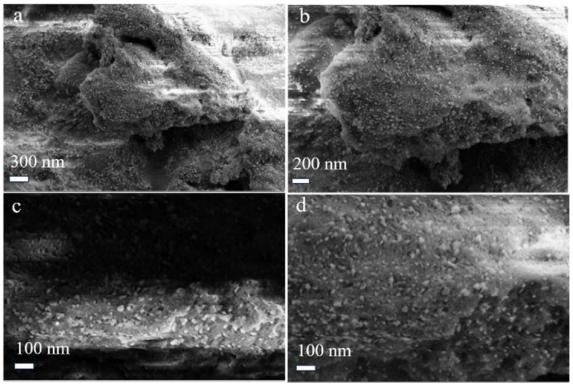


Figure 3: FE SEM images of Ag NPs at different magnifications.

Due to the presence of weak attracting force existing between the nanoparticles in the FE-SEM analyte, the agglomeration of particle occurred with incomplete separation[16]. It was the reason why the sample appeared as a single lump of analyte during the FE-SEM analysis. As the photocatalyst mixed with the reaction mixture is ultrasonicated for some minutes before catalytic application, the agglomeration as observed in FE-SEM images was expected to have negligible effects against the catalytic activity of Ag NPs[17].

HR-TEM Analysis

High resolution transmission electron microscopy (HR-TEM) was performed to identify the shape and size of synthesized silver nanoparticles (which were revealed as irregular crystalline structure) along with the study of their microstructure. In order to find the shape, size and aggregation of synthesized nanoparticles, HR-TEM characterization was very effective. The particle size of Ag NPs accompanied with the phytochemicals from ginger rhizome extract was found to be within the range of 5-100 nm. The Ag NPs were observed in different forms ranging from spherical to tetragonal. The nanoparticles thus obtained were less aggregated with smaller size. Although the formed Ag NPs were not much aggregated, they were seen interconnected forming the cage or net-like structures.

Result obtained from HR-TEM analysis was found consistent with the results reported in literature[18].

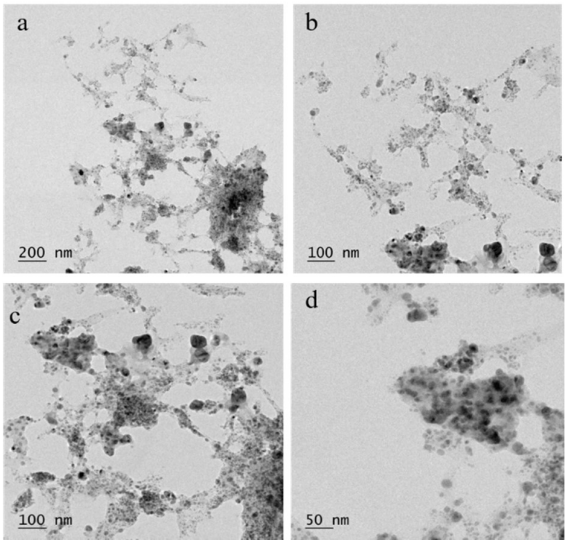


Figure 4: HR-TEM images of Ag NPs.

X-ray Diffractometric (XRD) Analysis

The crystal structure and the crystallinity of the as-constructed silver nanoparticles were analyzed through X-ray diffractometric probes and the corresponding profile is demonstrated in Figure 5. With the help of X-ray diffractometric analysis, the phase geometry of synthesized silver nanoparticles was analyzed thoroughly. The XRD diffraction peaks indicated that nanoparticles extracted from ginger rhizome extract were clearly crystalline in nature. The satellite peaks seen in the XRD pattern may be attributed to the different impurities present in the analyte[19,20].

The XRD pattern of the synthesized nanoparticles demonstrated different peaks in different sets of lattice planes. XRD pattern showed the diffraction peaks at 38.37, 46.19, 47.56 and 76.85° 2Ɵ values corresponding to (111), (200), (220) and (311) crystallographic planes of silver nanoparticles, respectively[3]. The additional intense peak appeared at 33.40 (2θ) (designated by *) may be assigned to the formation of Ag oxide in the form of a complex compound[3]. Sherrer's formula was used to determine the approximate crystallite size of the as-prepared silver nanoparticles[21]. The highly intense peak obtained at 46.19° (2Ɵ position) was used for the calculation of crystallite size of silver nanoparticles.

The approximate size of crystallites as determined by employing Scherrer's equation using the FWHM value

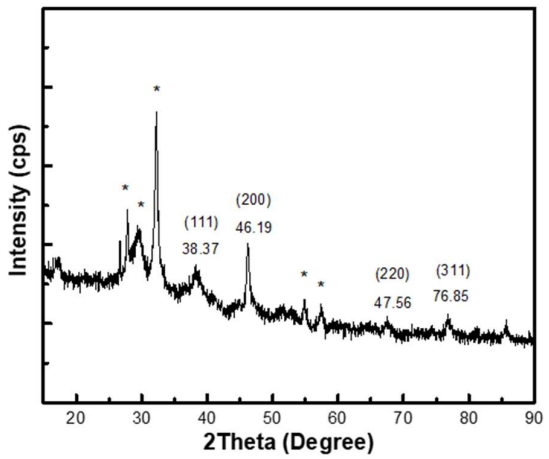


Figure 5: XRD pattern of as-synthesized Ag NPs.

from the most intense XRD peak of Ag NPs was found to be approximately 14 nm. Since the crystallite size calculation based on the XRD peak gives the only the approximate values, the grain size was determined from the HR-TEM analysis of the synthesized nanoparticles.

As Scherrer's equation gives an estimate of the mean size of the ordered crystallites (which may be smaller or equal to the grain size), it is desirable to use the FWHM value from the most intense XRD peak only to compute the approximate crystallite size. Moreover, crystallite size is not necessarily the same as the particle size (overall size of the nanomaterial)[16]. Therefore, the Scherrer's equation was used to estimate the size of crystallites.

In the XRD analysis, the as-synthesized silver nanoparticles displayed the crystallinity as asserted by the distinct peaks in the range of 38 to 77° range of 2Θ values. The resulting diffraction pattern of the as-synthesized sample was compared with that reported in the literature; which supported the existence of crystalline Ag NPs[3].

FTIR spectroscopic studies

FTIR reveals the possible functional molecules present in the given plant extract which were responsible for the synthesis of silver nanoparticles from reduced silver ions. Due to the excitation of surface plasmon resonance (SPR), Ag NPs exhibit yellowish-brown colour. FTIR analysis was employed to identify the potential phytochemicals in the ginger rhizome which are responsible for the reduction and stability to the ginger rhizome extract-mediated silver nanoparticles.

FTIR spectrum (Figure 6(i)) reveals different absorption peaks which were centred at 3358, 2128, 1640 and 1277 cm^{-1} lying in the range of 1000-200 cm^{-1}. Absorption peaks at 1637 and 1593 cm^{-1} results from stretching vibration of -C=O (ester). FTIR spectra reveal that the wide spectrum peaks were observed at 3358 and 3349 cm^{-1}. Peaks prominent at 1637 and 1593 cm^{-1} can be attributed to the stretching vibration of -C=O.

Different phytochemicals contain different functional groups which act as natural capping and stabilizing agents for the synthesis of silver nanoparticles. Oxygen atoms present in the heterocyclic compound directly support the stabilization of silver nanoparticles[8].

FTIR spectroscopic analysis (Figure 6 (ii)) showed prominent peaks at 3349, 1503, 1380, 1024 and 634 cm^{-1} because of the groups present in silver nanoparticles. Similarly, ginger rhizome extract showed intense peaks at 3368, 2188, 1640, 1277, 553 cm^{-1}, respectively. During FTIR analysis of Ag NPs, strong and broad peak was obtained at 3349 cm^{-1} and was attributed to stretching vibration of amine group (-NH) or hydroxyl (-OH) group and aliphatic C-H group of ginger rhizome root extract. Similarly, the peak at 1640 cm^{-1} represents the carboxyl group (-C=O) stretching vibration.

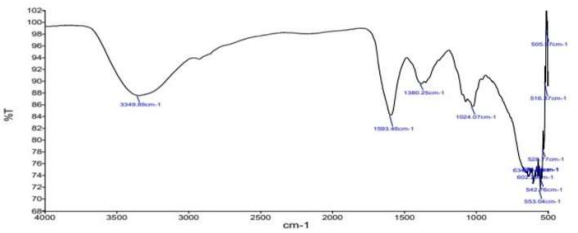


Figure 6: (i) FTIR spectrum of synthesized silver nanoparticles.

Peak at 1375-1420 cm^{-1} indicates the presence of $-NO_3$ group which existed in residual form[17].

Photocatalytic degradation of methylene blue

Visual observation

In the presence of solar radiation, photocatalytic degradation of methylene blue was successfully completed

by using green synthesized silver nanoparticles. Fading in

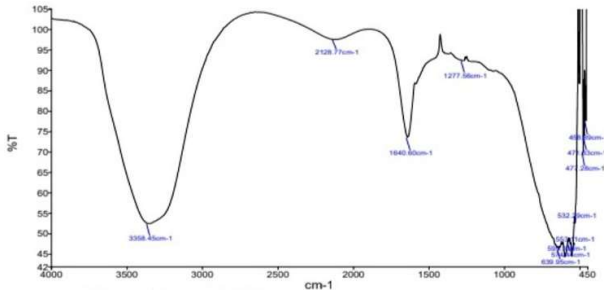
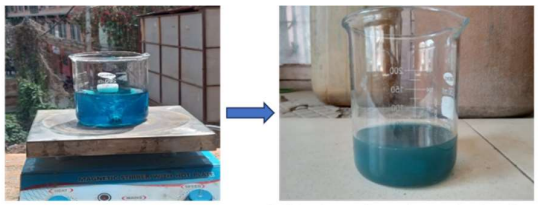


Figure 6: (ii) FTIR spectrum of ginger rhizome extract.

initial colour of the solution indicated the degradation of dye solution in the presence of photocatalyst and sunlight.

The initial dark blue colour of the methylene blue solution was changed into light blue after agitating with Ag NPs in the presence of sunlight for 2 hours. The visual colour change has been presented in Figure 7.



MB before photodegradation **MB after photodegradation by Ag NPs for 120 minutes**

Figure 7: Colour change observation during photocatalysis.

Photocatalytic degradation of MB solution

The photocatalytic activity of Ag NPs up on methylene blue in the presence of natural sunlight was performed effectively. MB solution with its ambient pH (pH = 6.54)[16] was used for all photocatalytic degradation experiments. Initially, for methylene blue solution, the decrease in peak intensity is obtained in the absorption spectrum. Increase in exposure time gradually decreased the absorption peak intensity of methylene blue dye approaching toward the base line. The gradual decrease in the absorption peak intensity with increasing exposure time indicated the photocatalytic degradation of methylene blue dye.

Different SPR bands for silver nanoparticles at 2 hours exposing time on sunlight was shown by UV-Vis spectra. The degradation efficiency for silver nanoparticles in terms of percentage was calculated as 57.8% upon 2 hours exposure on sunlight. On increasing the exposure time of reaction mixture on sunlight, the percentage of degradation was found to increase gradually.

Different graphs were obtained from UV-Vis absorbance spectra of the MB solution measured after regular interval of time. The graphs are presented in Figure 8. The figure displays the photocatalytic potential of Ag NPs. The photodegradation efficiency of silver nanoparticles upon methylene blue in the presence of solar irradiation was 57.85% for 0.012 g dose of photocatalyst per 100 mL of the dye solution. Since the 0.012 g dose of Ag NPs showed the best photocatalytic activity, this dose was used for further test and analysis. The diminishing intensity of absorption peak of MB dye revealed that the catalytic efficiency of nanoparticles exhibited excellent photocatalytic degradation in presence of natural sunlight[22].

Dose optimization of photocatalyst (Ag NPs)

Initially, three different doses; quantitatively, 0.0080 g, 0.012 g and 0.020 g of Ag NPs for every 100 mL of the dye solution were tested separately for photocatalytic degradation of MB and the corresponding results are presented in Figure 8 (b) to (d).

For photocatalytic experiments, 0.012 g of photocatalyst dose per 100 mL of MB solution was chosen randomly. In order to identify the optimum dose of photocatalyst, other varying doses of photocatalyst were also examined. The photodegradation of methylene blue solution was found to be 53.8%, when the mass of photocatalyst was increased to 0.020 g. When the mass of the photocatalyst was decreased to 0.0080 g, the photodegradation of methylene blue was observed to be 34.2%. Hence, the optimum dose of photocatalyst was found to be 0.012 g per 100 mL of MB solution during photocatalytic degradation.

Greatest photodegradation of MB was achieved when the photocatalyst dose was 0.012 g per 100 mL of dye solution. The effectiveness of the Ag NPs photocatalyst decreased when the dose was increased to 0.020 g and decreased to 0.0080 g. It was due to the fact that the dose of 0.012 g of Ag NPs was sufficient for higher dispersion as well as availability of higher active sites for photocatalytic degradation of methylene blue[17]. On contrary, greater amount of Ag NPs resulted in agglomeration and/or

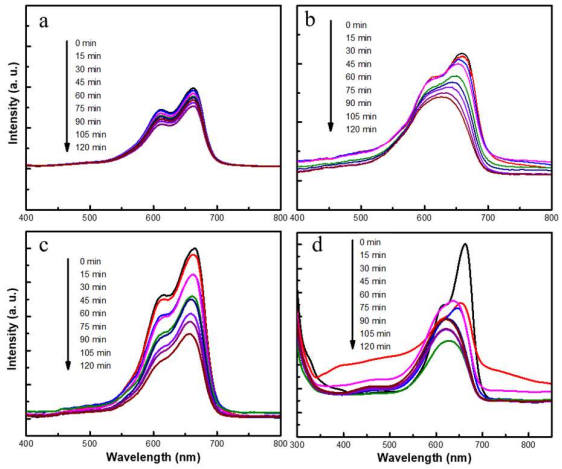


Figure 8: Photocatalytic degradation of 100 mL of MB solution by (a) photolysis (blank test), (b) 0.020 g of Ag NPs, (c) 0.0080 g of Ag NPs and (d) 0.012 g of Ag NPs.

reduced transparency of the reaction medium which ultimately reduced the rate of photocatalytic degradation by limiting the access of light to the reaction site[23].

A blank test was performed in order the examine the photodegradation of methylene blue in the absence of photocatalyst and the corresponding result is presented in Figure 8 (a). The photodegradation of MB accessed from blank test was found to be 12.67% which was compared with the effectiveness of green synthesized silver nanoparticles. Figure 8 (a) reveals that the photodegradation of MB in the absence of photocatalyst was found to be nearly negligible. Self-degradation of methylene blue (photolysis) occurs in the presence of sunlight because of self-sensitization; however, the effect is very low[19,20].

A proposed mechanism of photocatalytic action of green-synthesized Ag NPs has been presented in Figure 9. When Ag nanoparticles are irradiated with sunlight, electrons in the Ag valence band (VB) get excited and jump to Ag conduction band (CB). As a result, electrons gather in the conduction band and corresponding holes are created in the valance band. Those electrons attack O_2 molecules dissolved in water to produce superoxide (O_2^-) radicals. The holes react with water or OH^- ions to produce powerful $OH^\cdot$ radicals. The O_2^- radicals react further to generate $OH^\cdot$ radicals. The $OH^\cdot$ radicals attack the dye molecules adsorbed on the Ag NPs and decompose them into harmless inorganic products such as H_2O, carbon dioxide and mineral acids[8,21].

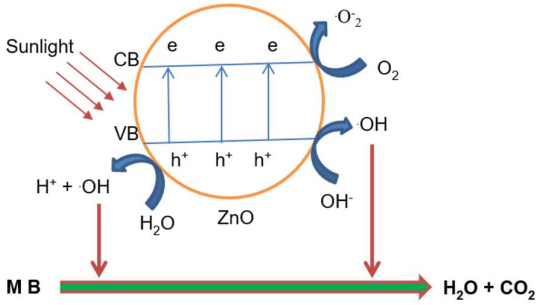


Figure 9: Proposed mechanism of photocatalysis of MB solution by Ag NPs.

Phytochemical screening

Qualitative phytochemical analysis generally explores the presence of total phytochemical constituents including alkaloid, flavonoid, saponin and terpenoid[7]. In the context, ginger is a traditionally used medicinal plant which is analyzed as the rich source of phenols, flavonoids, alkaloids, and tannins that act as stabilizing and reducing agent during the synthesis of Ag NPs[12]. Results of phytochemical screening of the ginger dry rhizome extract is presented in Table 1.

Table 1: Results of phytochemical screening of the dry ginger rhizome extract.

Chemical Constituents	Aqueous Ginger Rhizome Extract
Molisch's test	+
Alkaloid	+
Saponin	+
Terpenoid	-
Flavonoid	+

Here, the plus (+) sign indicates the presence of given phytochemical and minus (–) sign indicates the absence of given phytochemical species.

For phytochemical screening, the ginger was washed with tap water, and the peel was removed from it. The cleaned rhizome was washed with double-distilled water to ensure its purity and left open in shady place for 10 days to dry up. Dry rhizome was crushed in a mixture grinder to turn into its powder form. About 100 grams of powdered rhizome was added to a 500-mL beaker containing 400 mL of

distilled water. The mixture was heated to 80 °C for 30 minutes and filtered using Whatman 41 filter paper to discard insoluble impurities. The resultant filtrate was labelled as ginger rhizome extract and stored at 4 °C.

Conclusions

The effectiveness of the use of phytochemicals present in the aqueous extract of ginger rhizome to synthesize silver nanoparticles was explored. The change in the initial transparent light-yellow colour into brown after 1 hour of reaction indicated the successful completion of green synthesis of Ag NPs. The UV-Vis spectrum of the Ag NPs synthesized by using ginger rhizome extract showed an absorption peak at 425 nm which was the characteristic absorbance peak of Ag NPs and confirmed the formation of Ag NPs. The FTIR analysis showed the peak which were around 3349 and 1503 cm^{-1} corresponding to the functional groups -NH, and -C=C, respectively. It showed the presence of different phytochemicals such as alkaloids, saponins and flavonoids available in the plant extract.

The result obtained from XRD pattern indicated the crystalline structure of Ag NPs. The crystallite size of the Ag NPs as determined from the most intense peak of the XRD pattern was approximately 14 nm. FE-SEM revealed the aggregated cluster form of silver nanoparticles. However, HR-TEM analysis revealed the shape, size and morphology of green synthesized Ag NPs along with the study of its crystalline structure. The Ag NPs were seen less aggregated with distinct shapes.

The as-synthesized Ag NPs exhibited excellent photocatalytic activity for the degradation of methylene blue. The optimum dose of synthesized Ag NPs resulted in 57.8% photodegradation of MB within 2 hours of exposure of the reaction mixture to the natural sunlight. The remarkable photocatalytic performance of the synthesized Ag NPs asserts that Ag NPs synthesized through the green route can be the suitable agents for the environmental detoxification through colourant dyes degradation.

Data Availability Statement

The data underlying this study will be made available by the corresponding author in response to requests through email.

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