Research Article

Anuja S. Kumar, Gayathri Madhu, Elza John, Shinoj Vengalathunadakal Kuttinarayanan, and Saritha K. Nair*

Optical and antimicrobial properties of silver nanoparticles synthesized via green route using honey

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Abstract: Among the various green synthesis methods for nanoparticle synthesis, the honey-mediated green synthesis of nanoparticles is a fast, safe, biocompatible, and cost-effective method. In the present work, we demonstrate the sunlight-induced honey-mediated synthesis of silver nanoparticles and report the effect of light intensity, its color, and exposure time on the formation of nanoparticles. The visual inspection followed by UV-Vis spectral studies was performed to confirm the formation of silver nanoparticles. The HRTEM measurement confirms the formation of poly-dispersed silver particles. We further report the excellent antimicrobial activity of the synthesized nanoparticles against various strains of bacteria, which is found to be comparable to that of the antibiotic drug of choice. Our study points to further research on the possibility of considering these green synthesized silver nanoparticles as an alternative to antibiotics.

Keywords: green synthesis, silver nanoparticles, antimicrobial activity, optical properties

1 Introduction

There have been rapid advances in nanotechnology in recent years. The increasing environmental issues related to the nanoparticle synthesis have attracted

the researchers toward the green synthesis of nanoparticles as a step toward a sustainable and eco-friendly environment. In the green synthesis of nanoparticles, green chemistry is integrated with nanotechnology to create an environment-friendly, cost-effective, and safe synthesis of nanomaterials using biological resources [1,2]. The different approaches of green synthesis make use of resources such as microbial systems, plant systems, and biological materials. The demand for green synthesis keeps on increasing since the production of nanoparticles is cost-effective and eco-friendly [3,4]. The synthesis of metallic nanoparticles by green route is gaining attention due to the growing microbial resistance of disease-causing microorganisms against antibiotics and metal ions. Researchers have reported green synthesis of metal nanoparticles such as silver, gold, platinum, and palladium [5–17]. More focus has been on silver owing to its unique properties [18].

The green synthesis of silver nanoparticles using honey has been reported [14,19–24] where honey act as both a reducing and a stabilizing agent [14,19,22]. The sunlight-induced, honey-mediated synthesis is an easy and fast method for the synthesis of silver nanoparticles [21,25]. Although the anticorrosion properties of such nanoparticles have been reported [21], the antimicrobial properties of nanoparticle synthesized by our method has not been reported to our knowledge. In our previous work [25], we made an attempt to determine the nanoparticle size by employing the Mie theory. In this work, we report on the optical properties and the antimicrobial activity of the silver nanoparticles synthesized using natural honey. The only chemical used in the synthesis is the source of Ag^+ ions; silver nitrate is used in this study. The influence of exposure time, light intensity, and color of incident light on the formation of nanoparticles is specifically mentioned. The antimicrobial activity is compared with that of an antibiotic drug of choice.

* Corresponding author: Saritha K. Nair, Mar Athanasius College (Autonomous), Kothamangalam, India, e-mail: sarita.k.nair@gmail.com

Anuja S. Kumar, Gayathri Madhu, Elza John: Mar Athanasius College (Autonomous), Kothamangalam, India

Shinoj Vengalathunadakal Kuttinarayanan: Optics & Spectroscopy Laboratory, Union Christian College, Aluva, India

2 Materials and methods

In this sunlight-induced honey-mediated synthesis, natural honey is the only material used other than the source of Ag^+ ions. The Ag^+ ions for the synthesis of silver nanoparticles are obtained from 0.1 M silver nitrate (AgNO_3).

In this work, 3 mL of honey was dissolved in 97 mL of distilled water to prepare 3% honey solution. Ten milliliters of this diluted honey was added to 10 mL solution of AgNO_3 . The mixture was continuously stirred using a magnetic stirrer until a completely miscible solution was obtained. The mixture was then exposed to bright sunlight. The sunlight-exposed sample was then subjected to optical characterization. Solutions prepared with commercially available honey were also studied.

Data were also collected to study the response of the solution to light intensity by preparing the sample in triplicate and keeping the reaction mixture under dark (no light), dispersed sunlight and direct sunlight conditions for 10 min. The aforementioned samples were then subjected to optical characterization.

To study the dependence of incident light color on the synthesis of silver nanoparticles, same samples were taken in beakers wrapped with blue, green, yellow, and red cellophane papers, with 10-min exposure to direct sunlight. These samples were then subjected to optical characterization studies.

2.1 Characterization

The first characterization of silver nanoparticles was by visual observation for color change of solution mixture. The color change to nearly a yellowish-brown indicates the formation of silver nanoparticles [26]. The UV-visible spectra were recorded on a PerkinElmer lambda 650 UV-Vis spectrometer at room temperature operated at a resolution of 1 nm with range between 200 and 900 nm using plastic cuvette. The HRTEM measurements were taken on Jeol/JEM 2100 high-resolution electron microscope. The antibacterial activity of the nanoparticles was determined by the agar well diffusion method.

3 Results and discussion

3.1 Visual inspection

The synthesis of silver nanoparticles was first characterized by visual inspection of color change of solution

Figure 1: Color change of the solution mixture with an increase in exposure time.

mixture. The sample solution was then subjected to the UV-Vis spectroscopic measurement to confirm the result [27].

On exposure to sunlight, the solution turned to yellowish-brown, indicating the reduction of AgNO_3 into silver nanoparticles. The color increased in intensity with the increasing time. Figure 1 shows the color change in the solution mixture on exposing to sunlight for different time durations. We can observe a gradual increase in the intensity of color with the increasing exposure time. This is indicative of an increase in the concentration of nanoparticles formed as is also evidenced in the increase in surface plasmon resonance (SPR) peak intensity of the corresponding UV-Vis spectra.

To confirm the role of sunlight in inducing the formation of silver nanoparticles, the sample was prepared in triplicate and was subjected to different lighting conditions. Figure 2 shows the solution mixtures under different lighting conditions for a duration of 10 min. Observing the color of the solutions, it can be said that the color change, indicating the formation of silver nanoparticles, has occurred only in the sample exposed to sunlight. This confirms the role of sunlight in inducing the formation of silver nanoparticles.

The dependence of silver nanoparticle formation on the wavelength of incident light was studied by covering the sample containers in colored cellophane papers and then subjecting to the direct sunlight. Visual inspection of the color change, indicating the formation of silver nanoparticles, was performed. Figure 3 shows the sample solutions after this experiment. It can be seen that blue and yellow show intense color compared with the green and red. This indicates that blue and yellow lights are more effective in the production of nanoparticles by our method.

Figure 2: Solution mixture under different light conditions.

Figure 3: Color change of the solution mixture with the change in the wavelength of the incident light.

3.2 UV-Vis spectra

To confirm the conclusions from visual inspection, UV-visible spectra were taken, which is widely used for metal nanoparticles characterization [28]. Metallic nanoparticles show characteristic optical absorption spectra in the UV-visible region called SPR. The UV-visible

absorption of silver nanoparticles exhibits maximum in the range of 400–500 nm [21].

The formation of silver nanoparticles in solutions of natural honey and AgNO_3 was confirmed by the UV-Vis spectroscopy analysis. The absorptions are attributed to the SPR of the nanoparticles resulting from the reduction of the Ag^+ ions in the aqueous solution of natural honey.

Figure 4: UV-Vis spectra of the solution mixture for different exposure times.

Figure 5: UV-Vis spectra of the solution mixture under different light conditions.

The broadening of the peak can be attributed to the formation of polydispersed silver nanoparticles in the solution mixture [29], which is confirmed by the HRTEM measurement. We determined a size of approximately 1 nm for the synthesized nanoparticles using the Mie scattering theory [25], which agrees with the size distribution obtained from HRTEM images shown in Figure 8.

The samples in Figure 1 show an increase in the intensity of color with the increasing exposure time. The UV-Vis spectra of these samples are compared in Figure 4. We can see the SPR peak in the samples, and also the intensity of the peak increases with an increase in exposure time. It has been reported that the intensity of the SPR peak is related to the concentration of nanoparticles [30,31]. This corroborates the conclusion from visual inspection of samples in Figure 1.

The samples prepared in triplicate were subjected to different lighting conditions to confirm the role of sunlight in inducing the formation of silver nanoparticles. Figure 5 shows the UV-Vis spectra of the samples in Figure 2, and it can be clearly seen that the SPR peak is present only in the sample exposed to the direct sunlight, which again corroborates the conclusion from the visual inspection of the samples in Figure 2. The optical band gap is obtained from the UV-Vis spectrum, see Figure 6. The higher band gap size of 3.8 eV indicates the smaller particle size corroborating our calculated particle size of approximately 1 nm using the modified Mie theory [32] as reported in our previous work [25]. From the broad peak in the UV-Vis spectra, it was assumed that the particles are polydispersed, which was further confirmed by the TEM analysis. Hence, the calculated value is a rough estimation of the size of the nanoparticle. Still it approaches the mean particle size as seen in the histogram of particle size distribution obtained from the TEM image.

Figure 6: The bandgap estimation for the spectrum of the sample exposed to direct sunlight, and see the UV-Vis spectrum in Figure 5.

Figure 7: UV-Vis spectra of the sample exposed to different wavelengths.

The visual study of samples shown in Figure 3 had indicated that blue and yellow lights are more effective in the production of nanoparticles. The higher SPR peak intensities shown in Figure 7 for samples covered with blue and yellow cellophane papers confirmed the result obtained by visual inspection as the intensity of the SPR peak is related to the concentration of nanoparticles.

Figure 8a shows the TEM image of the sample. It can be seen that the nanoparticles are polydispersed. Figure 8b shows the histogram of the particle sizes obtained from Figure 8a. It can be seen that the mean particle size matches the rough approximation from the modified Mie theory. Lattice planes of the silver nanocrystallites corresponding to Ag(111) are clearly visible in the detailed high-resolution TEM image shown in Figure 8c. The selected area electron diffraction (SAED) pattern in Figure 8d also indicates that the nanoparticles are crystalline and polydispersed.

We have also observed that the intensity of the SPR peak depends on the type of cuvette used and also on the source of the natural honey. We could observe higher intensity with the use of quartz cuvette than with the plastic cuvette for the same sample as shown in Figure 9. A variation in SPR peak intensity was observed also for a sample prepared with differently sourced natural honey, which is not detailed as it is out of the scope of our study.

4 Antimicrobial activity

Antimicrobial activity of the nanoparticles was determined by the agar well diffusion method. The antimicrobial

Figure 8: (a) TEM image, (b) histogram of particle sizes obtained from the TEM image, (c) HRTEM image, and (d) SAED pattern.

activity is estimated from the zone of inhibition [33,34]. The zones of inhibition of the antibiotic disc amikacin, silver nanoparticle solution, and the control honey solution are shown in Figure 10. The diameter of the zone of inhibition around amikacin and silver nanoparticle solution against the test strains is shown in Table 1. The green synthesized silver nanoparticles showed excellent antimicrobial activity against *Escherichia coli*, *Klebsiella*, and *Staphylococcus aureus*, and Figure 10 shows the zone of inhibition comparable to that of the antibiotic drug of choice. The zone of inhibition in each

case was more than that of the control honey solution. The maximum zone of inhibition of 18 mm was found against *Klebsiella*.

5 Conclusions

We have demonstrated that the use of natural honey can produce silver nanoparticles when exposed to sunlight, thus avoiding the use of toxic chemicals. Sunlight is

Figure 9: UV-Vis spectra of the same sample using cuvettes made of quartz and plastic.

used to accelerate the synthesis of silver nanoparticles in the solution containing 0.1M AgNO_3 and honey. The color change of the solution indicates the formation of silver nanoparticles, and it is further confirmed by the surface plasmon resonance peak obtained in the UV-Vis spectra. We have confirmed the role of sunlight in inducing the formation of nanoparticles. The formation of nanoparticles is dependent on the exposure time to sunlight and the color of the incident light. The higher band gap energy indicates the formation of nanoparticles of smaller size. The silver nanoparticles synthesized showed the inhibition zone against *E. coli*, *Klebsiella* and *S. aureus* comparable to that against antibiotic drug of choice, thus showing the excellent antimicrobial activity of the synthesized nanoparticles. Our study points to further research on the possibility of considering these

Table 1: The antibacterial activity of silver nanoparticles (Ag NPs) synthesized using natural honey.

Organism	Zone diameter (mm)	
	Ag NPs	Antibiotic (amikacin)
<i>E. coli</i>	16.5	20
<i>Klebsiella</i>	18	20
<i>S. aureus</i>	17	24

green synthesized silver nanoparticles as alternative to antibiotics.

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Figure 10: Zone of inhibition against *E. coli*, *Klebsiella*, and *S. aureus*.

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