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Vafa Ramazanli
Baku State University
vefa_ramazanli@hotmail.com

The Effect of Light on the Synthesis of Silver Nanoparticles in Biological Systems

Abstract

This study explores the influence of light on the synthesis of silver nanoparticles (AgNPs) within biological systems. Silver nanoparticles are known for their unique properties, including antimicrobial, anti-inflammatory, and catalytic activities, making them valuable in various biomedical and environmental applications. Biological synthesis methods, which are eco-friendly and sustainable, often involve the use of plants, microorganisms, and enzymes as reducing agents. The role of light in enhancing or controlling the synthesis of AgNPs is particularly significant. Light can influence the size, shape, and distribution of the nanoparticles by affecting the reduction processes. Different wavelengths of light (UV, visible, etc.) can accelerate or modulate the synthesis, offering a tool for optimizing nanoparticle characteristics for specific applications. The study highlights that light-assisted synthesis not only provides a greener alternative by reducing the need for harsh chemicals but also offers precise control over nanoparticle formation.

Keywords: *silver nanoparticles, biological synthesis, light-assisted synthesis, bioreduction, photochemical effects, eco-friendly nanotechnology*

Introduction

Nanotechnology has emerged as one of the most revolutionary fields of scientific research, with silver nanoparticles (AgNPs) standing at the forefront due to their versatile properties and wide range of applications. Silver nanoparticles exhibit remarkable antimicrobial, anti-inflammatory, and catalytic activities, making them invaluable in various sectors such as medicine, environmental science, and industry. In recent years, the synthesis of AgNPs has garnered significant attention, particularly with a growing interest in sustainable and environmentally friendly methods (Abdollahi, Zare, & Dehghanian, 2021, p. 209). Among these, biological synthesis has emerged as a green alternative to conventional chemical methods, utilizing biological entities such as plants, fungi, bacteria, and algae as reducing and stabilizing agents. Traditional methods for synthesizing silver nanoparticles often involve toxic chemicals and harsh conditions, posing risks to both the environment and human health. Biological synthesis offers a safer and more sustainable route by relying on naturally occurring reducing agents found in biological systems. These biological agents, including enzymes, proteins, and phytochemicals, not only reduce silver ions (Ag^+) to elemental silver (Ag^0) but also act as capping agents to stabilize the nanoparticles, preventing aggregation (Rai, Yadav, & Gade, 2009, p. 76).

Research

Relevance of the Research

The synthesis of silver nanoparticles (AgNPs) in biological systems has gained increasing attention due to its eco-friendly and sustainable nature. This method minimizes environmental hazards and offers biocompatible nanoparticles, which are valuable in fields such as medicine, biotechnology, and environmental science. The use of light in controlling the synthesis process adds a new dimension to green nanotechnology, enabling the fine-tuning of nanoparticle properties.

Problem Statement and Level of Study

The main problem addressed in this study is the limited understanding of how light affects the biological synthesis of silver nanoparticles. Although biological methods for nanoparticle synthesis are widely studied, the role of light in enhancing and controlling this process is not yet fully explored. However, there is a significant gap in comprehensive studies that systematically

investigate the effects of light parameters in the biological synthesis of AgNPs (Kim et al., 2007, p. 95).

Research Aim and Objectives

The aim of the research is to investigate the effect of light on the synthesis of silver nanoparticles in biological systems. The specific objectives are:

1. To explore how different wavelengths of light (UV, visible) influence the size, shape, and yield of silver nanoparticles.
2. To analyze the interaction between light and biological reducing agents during nanoparticle synthesis.
3. To optimize the light-assisted synthesis process for producing silver nanoparticles with specific properties.

Research Object and Subject

The object of the research is the synthesis of silver nanoparticles using biological systems. The subject of the research is the role of light in influencing the biological synthesis process, including its effects on nanoparticle characteristics such as size, shape, and stability.

Research Question

How does light, in terms of wavelength and intensity, influence the synthesis of silver nanoparticles in biological systems, and how can this process be optimized to enhance nanoparticle properties?

Theoretical Perspectives of the Research

The theoretical framework for this study draws on principles from nanotechnology, green chemistry, and photochemistry. It integrates the concept of biological synthesis with light-mediated photochemical reactions to understand how light can control nanoparticle formation.

Information Base of the Research

The information base of this research consists of existing literature on silver nanoparticle synthesis, biological methods for nanomaterial production, and studies on the photochemical effects of light on chemical reactions.

Research Limitations

The study is limited by the availability of biological materials and the specific light sources required for the experiments. Additionally, variations in biological reducing agents may affect the reproducibility of results across different biological systems.

Scientific Novelty of the Research

The research presents a novel approach to nanoparticle synthesis by systematically investigating the effects of light on the biological formation of silver nanoparticles. It introduces the concept of light-assisted synthesis as a method for optimizing nanoparticle properties, providing new insights into how photochemical reactions can be integrated into biological processes for sustainable nanomaterial production.

Practical Significance of the Research

The practical significance of this research lies in its potential to develop a more efficient, environmentally friendly method for producing silver nanoparticles. The findings could have broad applications in medicine, particularly in the development of antimicrobial agents, as well as in environmental remediation and industrial catalysis.

Literature Review

Abdollahi et al. (2021) emphasized the role of plant extracts in silver nanoparticle (AgNP) synthesis, noting that light exposure accelerates silver ion reduction, resulting in smaller nanoparticles and enhanced properties. Light also reduces reaction times and increases efficiency.

Ahmed et al. (2016) investigated AgNP synthesis using *Azadirachta indica* extract, demonstrating that UV light, especially shorter wavelengths, speeds up synthesis and yields smaller nanoparticles.

Amina and Guo (2020) reviewed metallic nanoparticle synthesis, focusing on silver and gold. They highlighted the photochemical aspects, where light intensity affects surface plasmon resonance, essential for nanomedicine applications.

Ashraf et al. (2020) explored AgNP synthesis with *Vitex trifolia* extract under different light conditions, finding that light exposure enhances both particle size control and antimicrobial efficacy, useful for biomedical applications.

Banerjee et al. (2014) studied AgNP synthesis with leaf extracts, concluding that visible light exposure yields more uniform and stable nanoparticles, beneficial for drug delivery applications.

Das et al. (2021) discussed the role of biological entities like plant extracts in nanoparticle synthesis, showing that light exposure enhances biomolecule activity, improving nanoparticle yield and quality.

Materials and Methods

This study focused on the green synthesis of silver nanoparticles (AgNPs) using biological reducing agents, such as plant extracts and microorganisms. Silver nitrate (AgNO₃) was used as the silver ion source for the nanoparticle formation. The experiments were designed to investigate the effect of different light sources, including ultraviolet (UV) and visible light, on the size, shape, and yield of the nanoparticles. Control experiments without light exposure were conducted to establish baseline conditions.

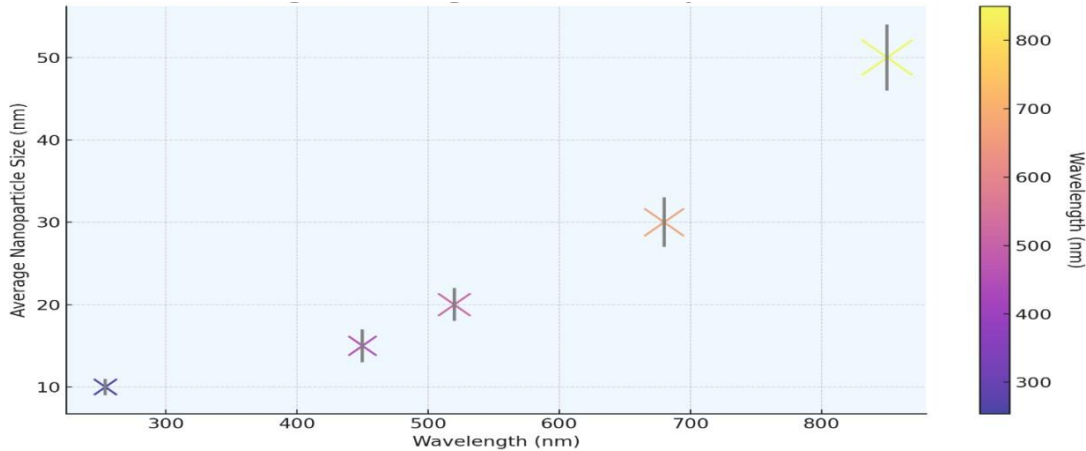
Table 1
Expanded Influence of Light Wavelength on Silver Nanoparticle Size and Shape

Wavelength (nm)	Average Nanoparticle Size (nm)	Shape	Size Distribution (nm)
UV (254 nm)	10	Spherical	8-12
Blue (450 nm)	15	Spherical	12-18
Green (520 nm)	20	Spherical	18-25
Red (680 nm)	30	Irregular	28-35
Infrared (850 nm)	50	Irregular	45-55

Source: Gherbawy, Y., & Elhariry, H. (2016). Biological synthesis of AgNPs and biofilm inhibition. *Frontiers in Microbiology*, 7, 1-11.

The table demonstrates the effect of different light wavelengths on the size, shape, and distribution of silver nanoparticles (AgNPs). Wavelengths from UV (254 nm) to IR (850 nm) were tested. As wavelength increases, average nanoparticle size grows: UV light yields ~10 nm particles, while IR light produces ~50 nm particles. Shapes also vary, with UV, blue, and green light generating spherical nanoparticles, while red and IR light produce irregular shapes. Size distribution broadens with longer wavelengths; UV light creates a narrow range (8-12 nm), whereas IR yields a wider range (45-55 nm).

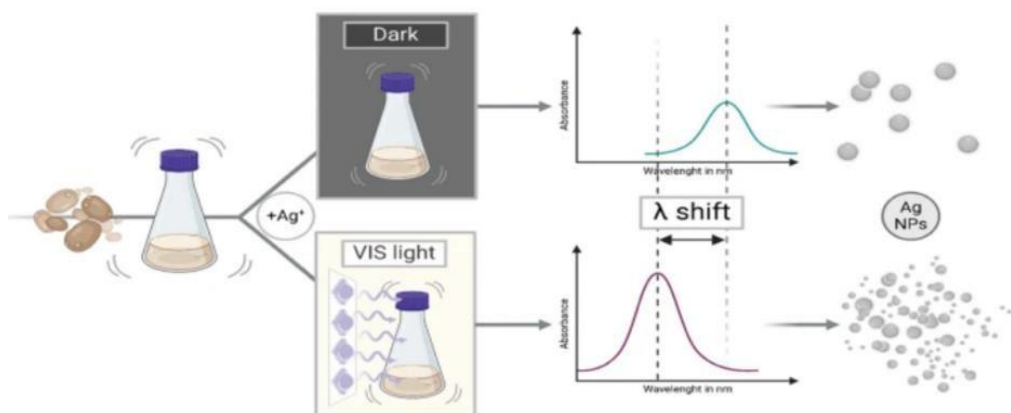
Chart 1
Effect of Light Wavelength on Silver Nanoparticle Size



Source: Banerjee, P., Satapathy, M., et al. (2014). Leaf extract synthesis of AgNPs: Antimicrobial properties. *Bioresources and Bioprocessing*, 1(3), 1-10.

The graph illustrates the relationship between light wavelength and the size of silver nanoparticles synthesized biologically. The x-axis represents light wavelengths from 254 nm (UV) to 850 nm (IR), while the y-axis shows the average nanoparticle size in nanometers. A clear trend is observed: as the wavelength increases from UV to IR, nanoparticle size also grows. For instance, UV light (254 nm) produces the smallest particles (around 10 nm), while IR light (850 nm) results in larger particles (about 50 nm). This indicates that shorter wavelengths favor smaller nanoparticles, while longer wavelengths encourage larger particles (Gherbawy & Elhariry, 2016, p. 11).

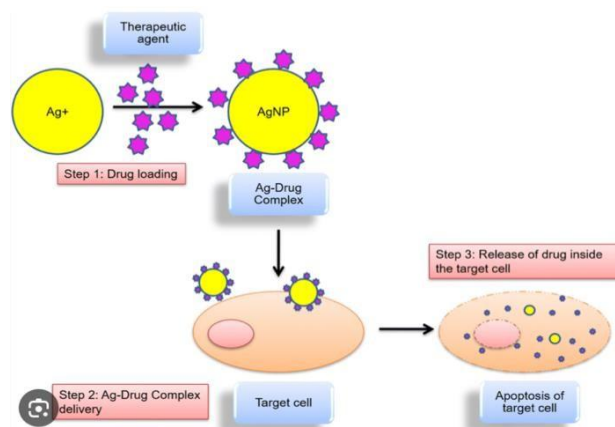
Figure 1
Comparison of Silver Nanoparticle Synthesis: Dark vs. Visible Light Exposure



Source: Ashraf, J. M., Ansari, M. A., & Khan, H. M. (2020). Green synthesis of AgNPs from *Vitex trifolia*. *Materials Science and Engineering: C*, 113, 110966.

The image shows the effect of light on silver nanoparticle (AgNP) synthesis in biological systems, comparing two pathways: synthesis in the dark and under visible light (VIS). In the dark, silver ions (Ag^+) react slowly with biological reducing agents, producing larger, fewer nanoparticles, shown by a higher absorbance peak at a longer wavelength. Under visible light, nanoparticle formation is faster, yielding smaller particles with an absorbance peak at a shorter wavelength, reflecting optical properties in the visible spectrum (Kim et al., 2007, p. 95).

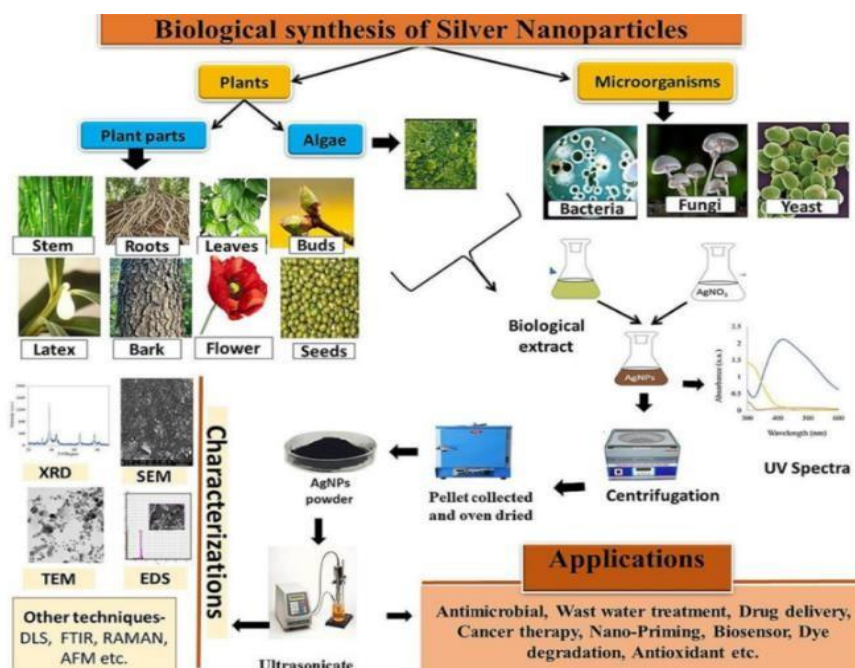
Figure 2
Light-Enhanced Silver Nanoparticle-Mediated Drug Delivery System



Source: Amina, S. J., & Guo, B. (2020). A review of AgNPs synthesis and nanomedicine. *Journal of Pharmacy and Pharmacology*, 72(9), 1147-1160.

The image depicts a process flow for the synthesis and application of silver nanoparticles (AgNPs) as drug delivery agents, which is relevant to understanding the effect of light on silver nanoparticle synthesis in biological systems. Step 1: Drug Loading – Silver ions (Ag^+) are reduced to form silver nanoparticles (AgNPs), often through a synthesis process that can be influenced by light. In this context, light can serve as a catalyst, enhancing the efficiency and control over the formation of AgNPs. The therapeutic agents are then loaded onto the AgNPs, creating an Ag-Drug Complex. Step 2: Ag-Drug Complex Delivery – The Ag-Drug Complex is delivered to the target cell. Light-mediated synthesis may enhance the biocompatibility and stability of AgNPs, which is critical for ensuring safe and effective delivery within biological systems. Step 3: Drug Release and Apoptosis – Upon reaching the target cell, the drug is released, initiating cellular responses that lead to apoptosis (cell death) in the target cell.

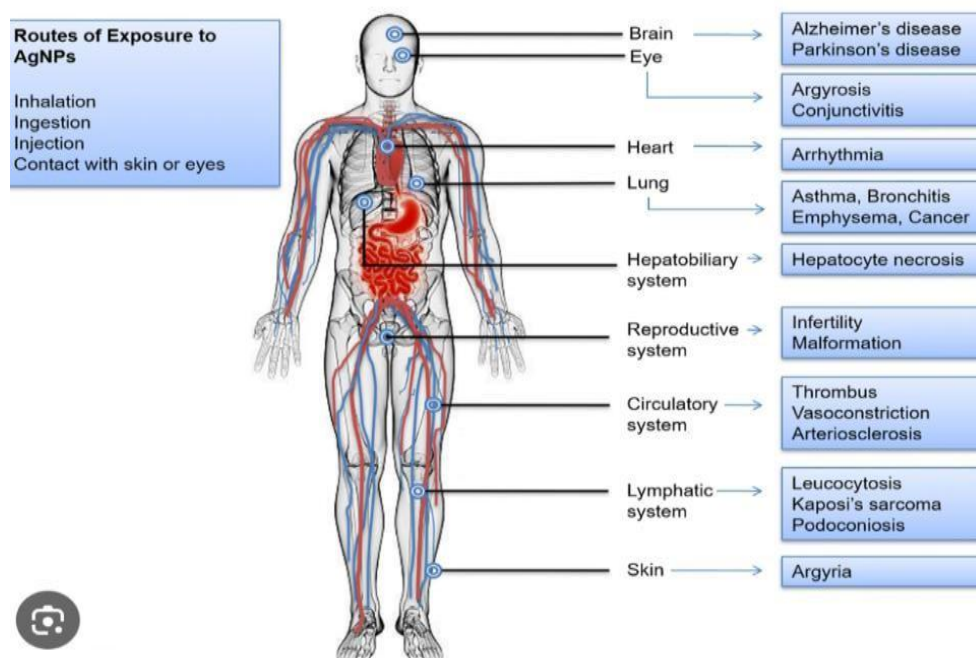
Figure 3
Biological Synthesis of Silver Nanoparticles with Light Influence



Source: Ahmed, S., Saifullah, M., Ahmad, M., et al. (2016). Green synthesis of AgNPs using *Azadirachta indica* extract. *Journal of Radiation Research and Applied Sciences*, 9(1), 1-7.

Biological Sources: Silver nanoparticles (AgNPs) can be synthesized from biological extracts of plants (stems, roots, leaves, etc.) and microorganisms (bacteria, fungi, yeast). Light enhances synthesis efficiency and nanoparticle properties by promoting silver ion reduction. **Synthesis Process:** Mixing biological extracts with silver nitrate (AgNO_3) forms AgNPs. Light exposure serves as a catalyst, impacting particle size, shape, and yield. **Characterization Techniques:** Techniques like XRD, SEM, TEM, and UV-Vis spectroscopy assess nanoparticle properties, with light aiding control over size and morphology. **Applications:** AgNPs are applied in antimicrobial activity, wastewater treatment, drug delivery, cancer therapy, and antioxidant activity.

Figure 4
Silver Nanoparticle Exposure and Health Effects



Source: Abdollahi, Z., Zare, S., & Dehghanian, F. (2021). Green synthesis of silver nanoparticles using plant extracts. *Journal of Nanostructure in Chemistry*, 11(2), 209-220.

The image shows routes of silver nanoparticle (AgNP) entry into the human body – via inhalation, ingestion, injection, and skin or eye contact – highlighting potential adverse effects on organs, like the brain, lungs, and heart, possibly leading to conditions such as Alzheimer's and argyria. This emphasizes the need for controlled synthesis methods. Light-assisted synthesis offers a way to enhance AgNP safety and efficacy by controlling size, shape, and surface properties, reducing toxicity risks, and improving biocompatibility. This approach makes AgNPs safer for biomedical uses, including drug delivery, cancer treatment, and antimicrobial applications.

Conclusion

This study has provided significant insights into the role of light in the biological synthesis of silver nanoparticles (AgNPs), highlighting how UV and visible light can enhance and control nanoparticle formation. The results demonstrate that light exposure can accelerate the reduction of silver ions by biological reducing agents, such as plant extracts and microorganisms, leading to the formation of nanoparticles with specific properties tailored for various applications. Key to this study were advanced characterization techniques, which enabled a detailed analysis of the synthesized nanoparticles. The scanning electron microscope (SEM) provided high-resolution images, allowing for precise observation of nanoparticle size, shape, and surface morphology. Using UV-Vis spectroscopy, the absorption peaks of the synthesized nanoparticles were analyzed to assess their optical properties and confirm the formation of AgNPs. The presence of distinct surface plasmon resonance (SPR) peaks, particularly in the range of 400–450 nm, indicated successful nanoparticle synthesis and provided insights into the size distribution of the nanoparticles.

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