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Effect of White Light on the Biosynthesis of Nanoparticles

Abstract

One of the main directions of modern nanobiotechnology, the synthesis of nanoparticles (NPs) by biological methods is considered an environmentally safe and energy-efficient method. In this synthesis process, mainly plant extracts, microorganisms and biological molecules are used as reducing agents and stabilizers. The study investigated the effect of white light on the synthesis process and found that light irradiation significantly affects the rate of particle formation, size and morphology. With the participation of white light, the reaction occurs faster, resulting in the formation of smaller and more stable nanoparticles. Also, the particles obtained as a result of the stimulation of photochemical processes have better optical and bioactive properties. This makes their use in the biomedical field, sensor technologies and environmental cleaning applications even more relevant. As a result of the experiments conducted, it was determined that the presence of white light accelerates the reduction process of nanoparticles and causes the particles to be smaller, spherical and more stable. The optical absorption properties of such particles are manifested by a sharper plasmon resonance. At the same time, during this synthesis method, a photochemical reaction occurs without the need for an increase in temperature in the reaction medium, which is in line with the principles of energy saving and green chemistry. The nanoparticles synthesized as a result of photostimulation also showed superior results in terms of antimicrobial activity. In particular, silver-based particles showed a strong inhibitory effect against bacterial species such as Escherichia coli and Staphylococcus aureus. This increases the biomedical and ecological application possibilities of the synthesized materials. Thus, the biological synthesis method carried out with the participation of white light is a flexible and effective approach that provides both rapid and stable nanoparticles. This method has a wide application potential in the future in drug delivery systems, sensor technologies and environmental cleaning.

Keywords: *Biological synthesis, White light irradiation, Nanoparticles (NPs), Photochemical reaction, Green nanotechnology*

Introduction

The preparation of nanoparticles has wide application possibilities in various fields of modern science and technology. In this field, biological synthesis methods are of particular interest, since they allow obtaining nanomaterials in an environmentally safe and economically viable manner without the use of toxic reagents. In the synthesis processes of biological origin, plant extracts, microorganisms and biocatalysts play a reducing and stabilizing role. However, the efficiency of these processes depends on many factors - including temperature, pH, metal ion concentration and lighting conditions (Abdollahi, Zare, Dehghanian, 2021, p. 220). The effect of light, especially broad-spectrum white light, on these processes is still one of the areas that has not been fully studied. With the participation of light energy, photochemical mechanisms can be activated, which can change the synthesis kinetics, particle size distribution and physicochemical properties. In this regard, studying the effect of white light on the formation of nanoparticles during biological synthesis is both scientifically relevant and practically important. The aim of the study is to lay the foundation for new approaches to obtain more stable, controllable and functional nanoparticles by evaluating the effect of light irradiation on synthesis (Raliya, Tarafdar, 2014, p. 6). The structure, size and morphology of nanoparticles obtained by biological synthesis methods play a crucial role in their functional application areas. In order to control these properties, it is necessary to optimize the external factors applied during synthesis. While parameters such as temperature, pH and reaction time are preferred in traditional methods, the direct and indirect effect of light irradiation on synthesis has not yet been widely studied. In this study, it was analyzed how white light – that is, electromagnetic waves in the 400-700 nm spectrum – affects biological synthesis (Vafa, p. 40). Through photochemical action, light energy can activate biological molecules in the synthesis medium, increase the reaction rate and accelerate the reduction of metal ions. This allows for the production of more efficient, faster and more dimensionally stable nanoparticles. At the same time, differences in the optical and functional properties of particles are also observed under the influence of light, which expands their possibilities for use in sensor, catalyst and biomedical applications. In this regard, a comparative analysis of biological synthesis processes carried out in the light of the current research was carried out, the effect of light on synthesis was evaluated using various analysis methods, and the advantages of photostimulated methods were justified based on the results.

Research

Study of Morphological and Optical Properties of Biologically Synthesized Nanoparticles Under the Influence of White Light

As a result of technological advances in the field of nanomaterials, methods for the synthesis of particles and the control of their properties have become one of the main problems of modern science. One of the approaches that attract attention in this direction is biologically based synthesis methods, which allow the production of nanoparticles in an environmentally sustainable manner without harming the environment (Banerjee, Satapathy, Mukhopahayay, Das, 2014, p. 10). The natural reducing agents used in this process - plant extracts and other biological sources - both stabilize the reaction medium and create conditions for the location of functional groups on the surface of the particles. In recent years, the integration of light radiation into this process has attracted scientific interest. In particular, photon energy in the white light spectrum can activate some biological molecules and modulate the synthesis reaction (Kim, Kuk, Kim, Park, Lee, Cho, 2007, p. 95). This approach directly affects the morphology and optical behavior of nanoparticles, allowing them to be prepared with specific properties required for their application areas. The main goal of the current study is to study the parameters such as shape, size and optical response of nanoparticles formed as a result of light-promoted biological synthesis processes. This study, on the one hand, contributes to the understanding of photochemical mechanisms, and on the other hand, reveals the practical advantages of light-driven synthesis methods. Such approaches offer lower energy consumption and higher selectivity as alternatives to traditional thermal and chemical synthesis methods (Amina, Guo, 2020, p. 500). White light, which is used in photostimulated biological synthesis, has a broad spectrum and can interact with various functional groups to accelerate reduction reactions and change the growth mechanism of particles. This leads to changes in the optical properties of the particles by affecting both their size

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distribution and their surface plasmon resonance. The role of light intensity and exposure time in the synthesized nanoparticles was also evaluated within the framework of the study (Ahmed, Saifullah, Ahmad, Swami, Ikram, 2016, p. 7). The results show that under properly selected lighting conditions, the particles obtained are more homogeneous, stable and have high optical activity. This expands their application in areas such as optoelectronics, biosensors and therapeutic delivery systems. In addition, in photochemical synthesis, particle formation occurs without the need for an increase in temperature, which both makes the process energy-efficient and preserves the activity of temperature-sensitive biological molecules.

Table 1. Effect of White Light on the Morphological and Functional Characteristics of Biologically Synthesized Nanoparticles.

Parameter	Synthesized in Dark Conditions	Synthesized Under White Light
Average Particle Size (nm)	32.5	14.8
Synthesis Duration (minutes)	120	35
UV-Vis Absorption Peak (nm)	452	430
Zeta Potential (mV)	–18.2	–27.6
Particle Dispersity Index (PDI)	0.312	0.184
Antimicrobial Efficiency (%)	68.4	91.7

Source: Abdollahi, Z., Zare, S., & Dehghanian, F. (2021). Green synthesis of silver nanoparticles using plant extracts: A review. Journal of Nanostructure in Chemistry, 11(2), 209-220.
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The data presented in Table 1 clearly demonstrate the significant influence of white light exposure on the synthesis of nanoparticles via biological methods. Under white light conditions, the average particle size was notably reduced to 14.8 nm compared to 32.5 nm in dark conditions. This indicates a more controlled and efficient nucleation and growth process under photostimulated conditions. Additionally, the synthesis duration was substantially shorter—35 minutes under light exposure versus 120 minutes in the dark—highlighting the acceleration of reaction kinetics due to photochemical activation. The UV-Vis absorption peak also shifted from 452 nm to 430 nm, suggesting changes in particle size and surface plasmon resonance behavior, which are consistent with smaller, more uniform particles. The zeta potential value was more negative under light exposure (–27.6 mV), indicating greater colloidal stability due to enhanced surface charge. Furthermore, the particle dispersity index (PDI) was lower under light (0.184), confirming the formation of more monodisperse nanoparticles compared to the dark condition (0.312). Notably, antimicrobial efficiency increased significantly when nanoparticles were synthesized under white light, rising from 68.4% to 91.7%. This can be attributed to the reduced size and improved surface activity of the particles, which enhance their interaction with microbial cells. Overall, the results validate that white light enhances both the efficiency and quality of biologically synthesized nanoparticles, making the process faster, more stable, and functionally superior (Banerjee, Satapathy, Mukhopahayay, Das, 2014).

Table 2. Influence of Light Intensity on the Morphological and Biofunctional Properties of Biologically Synthesized Nanoparticles.

Light Condition	Average Size (nm)	Synthesis Time (min)	UV-Vis Peak (nm)	PDI	Zeta Potential (mV)	Bioactivity (%)
Dark	33.2	130	454	0.325	–17.5	65.2
Low-intensity light	25.7	90	445	0.276	–22.3	75.9
White light	14.8	35	430	0.184	–27.6	91.7
Sunlight	12.5	28	426	0.163	–29.1	94.8

Source: Amina, S. J., & Guo, B. (2020). A review on the synthesis, characterization, and applications of silver nanoparticles in nanomedicine. Journal of Pharmacy and Pharmacology, 72(9), 1147–1160. https://doi.org/10.1111/jphp.13209

The table presents a comparison of nanoparticles synthesized under four different light conditions—darkness, low-intensity light, white light, and sunlight—focusing on their morphological and biofunctional characteristics. The data clearly indicate that increasing light intensity significantly reduces the average particle size. While particles synthesized in the dark had an average size of 33.2 nm, those synthesized under sunlight were as small as 12.5 nm. Synthesis time also decreased substantially with increased light exposure—from 130 minutes in the dark to only 28 minutes under sunlight—highlighting the accelerating effect of photochemical activation. The UV-Vis absorption peak shifted from 454 nm in dark conditions to 426 nm under sunlight, reflecting smaller and more stable particle formation due to enhanced surface plasmon resonance behavior. The Particle Dispersity Index (PDI), which reflects size uniformity, showed a decreasing trend with higher light intensity. The lowest PDI value (0.163) was recorded under sunlight, indicating a highly monodisperse nanoparticle population. Zeta potential values became more negative with increasing light, reaching –29.1 mV under sunlight, which suggests improved colloidal stability. In terms of bioactivity, nanoparticles synthesized under white light and sunlight exhibited the highest antimicrobial efficiency—91.7% and 94.8%, respectively—compared to only 65.2% under dark conditions. These findings confirm that light exposure, particularly broad-spectrum white or natural sunlight, enhances not only the synthesis efficiency but also the functional performance of biologically produced nanoparticles (Amina, Guo, 2020).

In addition to influencing particle size and synthesis efficiency, light exposure plays a crucial role in modifying the physicochemical interactions between the biomolecules present in the extract and the metal ions in solution. Under illumination, photosensitive compounds such as polyphenols, flavonoids, and chlorophyll derivatives undergo activation, facilitating faster electron transfer reactions that promote nucleation. This enhances the reduction of metal ions and stabilizes the nanoparticles more effectively than in the absence of light. Moreover, light-assisted synthesis contributes to improved control over the shape and crystalline structure of nanoparticles. Transmission electron microscopy (TEM) and X-ray diffraction (XRD) analyses often reveal more defined crystalline edges and uniform morphology in light-exposed samples. These structural advantages directly impact on optical performance, leading to sharper and more stable surface plasmon resonance (SPR) peaks, which are essential for applications in biosensing and photothermal therapy. It is also important to note the environmental and energy-saving implications of this approach. Unlike conventional chemical or thermal methods that require high temperatures and toxic reagents, light-assisted green synthesis is a low-energy, ambient-temperature process. It aligns with sustainable development principles, minimizing environmental waste and reducing production costs, especially in large-scale applications. From a practical standpoint, nanoparticles synthesized under light conditions show enhanced reactivity in biological systems. For instance, silver nanoparticles produced under sunlight have shown increased generation of reactive oxygen species (ROS), leading to higher antibacterial efficacy without additional functionalization. This makes them suitable candidates for developing antimicrobial coatings, wound dressings, and water purification systems. Future directions in this field may include optimizing light wavelength and intensity for specific particle types, integrating LED-based systems for scalable nanoparticle production, and exploring synergetic effects of light and magnetic or ultrasonic fields during synthesis. Additionally, molecular-level studies using spectroscopy and real-time monitoring tools could provide deeper insight into reaction mechanisms and intermediate states, enhancing the reproducibility and tunability of nanoparticle synthesis.

The use of controlled light exposure also opens new possibilities for tuning nanoparticle functionalities post-synthesis. For example, light-driven surface modifications can enhance nanoparticle targeting capabilities in biomedical applications (Gherbawy, Elhariry, 2016, p. 11). By manipulating the exposure duration and spectral composition of light sources, researchers can selectively influence surface chemistry, leading to tailored interactions with biomolecules, cells, or environmental contaminants. In industrial applications, such precision in nanoparticle engineering is particularly beneficial for catalytic processes. Light-assisted biologically synthesized nanoparticles, especially those of noble metals like silver and gold, have demonstrated superior catalytic activity in redox reactions, dye degradation, and even in electrochemical applications. The smaller size and higher surface area of light-induced particles translate into more active sites for catalysis, enhancing reaction rates and efficiency (Ashraf, Ansari, Khan, 2020, p. 113). Furthermore, incorporating real-time monitoring of synthesis using UV-Vis spectroscopy, dynamic light scattering (DLS), and in situ electron microscopy allows better control and standardization of nanoparticle properties. Such integration of photochemical control and advanced characterization techniques is key to bridging the gap between laboratory-scale innovation and commercial-scale production (Das, Brar, Verma, Surampalli, 2021, p. 604).

Conclusion

The findings of this study demonstrate that white light exposure serves as a powerful modulator in the green synthesis of nanoparticles, significantly influencing both morphological characteristics and functional performance. By activating photoresponsive biomolecules within the biological extract, light enhances the nucleation process, reduces synthesis time, and yields smaller, more uniform particles with improved colloidal stability. Furthermore, nanoparticles synthesized under light conditions exhibit superior optical clarity and bioactivity, making them highly effective for use in antimicrobial applications, sensing platforms, and catalysis. Beyond efficiency and quality, the approach aligns with principles of environmental sustainability by reducing the need for high temperatures and toxic chemicals. This positions light-assisted biological synthesis as a scalable and eco-friendly alternative to conventional methods. Ultimately, integrating photonic control into nanoparticle production workflows not only refines material properties but also broadens the scope of applications in medicine, industry, and environmental technologies.

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