OPEN ACCESS
Haya: The Saudi Journal of Life Sciences
Abbreviated Key Title: Haya Saudi J Life Sci
ISSN 2415-623X (Print) | ISSN 2415-6221 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: https://saudijournals.com

Review Article

The Latest Studies for the Manufacture of Nanoparticles in Iraq during the Last Ten Years Ago

Marwa Amin Al-Rawi[1*], Ghuffran Muhammed Hassan[2], Hayfaa Mahmood Fahad[3]

[1]Department of Medical Microbiology, College of Medicine, Al-Iraqia University, Baghdad, Iraq
[2]Department of Biology, Collage of Science, University of Baghdad, Al-Jaderiya Campus, Baghdad, Iraq
[3]Department of Microbiology College of Medicine AL Iraqia University

DOI: 10.36348/sjls.2024.v09i04.001 | **Received:** 17.02.2024 | **Accepted:** 28.03.2024 | **Published:** 09.04.2024

***Corresponding author:** Marwa Amin Al-Rawi
Department of Medical Microbiology, College of Medicine, Al-Iraqia University, Baghdad, Iraq

Abstract

Silver nanoparticles (AgNPs) have gained immense consideration recently as a result of their exceptional properties and diverse interference in a variety of fields. The AgNPs synthesis involves various and biological, chemical, and physical methods, each offering distinct compensations in terms of size control, stability, and reproducibility. Physical methods, such as irradiation, result in monodisperse nanoparticles with excellent control over size and shape. Chemical techniques, like reduction with reducing agents or chemical precursors, offer scalability and control over nanoparticle size. Moreover, green synthesis methods employing plant extracts, fungi, and bacteria have emerged as eco-friendly alternatives, reducing the reliance on hazardous chemicals. Characterization of AgNPs is necessary to understand their characteristics and potential applications fully. Techniques such as X-ray diffraction (XRD), UV-Vis spectroscopy, light scattering (DLS), transmission electron microscopy (TEM), and scanning electron microscopy (SEM), dynamic are commonly used to identified anf characterized the nanoparticles. The applications of AgNPs span across several sectors. In the biomedical field, AgNPs exhibit potent antimicrobial properties against a broad spectrum of pathogens, making them promising candidates for wound dressings, antibacterial coatings, and drug delivery systems. Additionally, their use in cancer therapy has shown potential for targeted drug delivery and localized hyperthermia treatment. However, despite their numerous applications, challenges remain in terms of toxicity and environmental impact. Research efforts are ongoing to address these concerns and develop safer nanomaterials. This review article concludes that silver nanoparticles represent a fascinating class of nanomaterials with immense potential in various fields. Continued research and development in the synthesis, characterization, and application of AgNPs will undoubtedly lead to new and exciting advancements in science and technology.

Keywords: AgNPs, Green Synthesis, Bioactivity, Cytotoxicity.

INTRODUCTION

Silver nanoparticles are tiny particles of silver that have a size lies between 1 to 100 nanometers (nm). Due to their unique properties and potential applications, they have garnered significant interest in various fields, including nanotechnology, biomedical sciences, electronics, and environmental engineering. Silver nanoparticles possess distinct physical, chemical, and biological characteristics that set them apart from bulk silver or other forms of nanomaterials [1, 2].

Key Characteristics of Silver Nanoparticles

Size and Shape:

AgNPs are typically in the range of 1-100nm, with a diversity of shapes such as rods, spheres, wires, triangles, and more. Their size and shape significantly influence their properties and applications [3].

Surface Area:

Silver nanoparticles exhibit enhanced reactivity, making them ideal for catalysis and other chemical processes, this is due to the tiny size and wide volume of surface [4].

Optical Properties:

The color of silver nanoparticles can change depending on their size and shape. This observable fact is recognized as the localized surface plasmon resonance (LSPR), which gives rise to various vibrant colors when light interacts with the particles [5].

Antibacterial Properties:

One of the most notable characteristics of silver nanoparticles is their potent antibacterial activity. They can interact with bacterial cell membranes and disrupt cellular processes, leading to the inhibition of bacterial growth. This feature has led to their use in various antimicrobial applications [6].

Applications of Silver Nanoparticles

Antimicrobial Coatings:

Silver nanoparticles are incorporated into coatings and surfaces to create antimicrobial properties for various applications, including medical devices, textiles, and household items [6].

Biomedical Applications:

Owing to their anti-inflammatory and antibacterial features, they are used in bandages, wound dressings, and other medical products to promote wound healing and prevent infections [7].

Nanotechnology:

Silver nanoparticles are employed as nanosensors and nanocatalystsin various chemical and biological reactions, due to their reactivity and high surface area [5].

Electronics:

Silver nanoparticles find applications in electronics, such as conductive inks for printed electronics and as conductive fillers in electronic components [8].

Water Treatment:

Silver nanoparticles can be used for water purification and treatment due to their ability to kill harmful bacteria and microorganisms [9].

Imaging and Diagnostics:

In medicine, AgNPs are being explored for their potential as afent of contrast in medical imaging and diagnostic techniques [5].

AgNPs Synthesis

AgNPs synthesis involves a variety of methods, each with its advantages and limitations. Here, I'll outline two commonly used techniques for producing silver nanoparticles:

Reduction Process

Reduction of silver ions is taking place to form silver nanoparticles. The reduction is typically achieved using a reducing agent in the existence of a stabilizing agent to avoid nanoparticle aggregation. Sodium borohydride method is one of the major popular examples to chemical reduction method, which involves the following steps [10]:

a. **Preparation of Ag Precursor**: Suitable solvent is usually used to dissolve silver saltlike ($AgNO_3$), among solvents that were used in this step is water in order to create a solution of silver ions.
b. **Addition of Reducing Agent**: A reducing agent, such as sodium borohydride (NaBH4), is slowly added to the Ag^+ solution. The electrons were donated frpm the reducing agent to Ag ions, leading to formation of silver atoms and the subsequently creation of AgNPs.
c. **Stabilization**: To prevent the AgNPs from agglomerating, a stabilizing agent, such as polyvinylpyrrolidone (PVP), may be added. The stabilizing agent binds to the nanoparticle surfaces, keeping them separate and preventing aggregation.
d. **Purification**: The resulting silver nanoparticle solution is then purified through techniques like centrifugation or dialysis to remove excess reagents and by-products.

Green Synthesis:

Green synthesis involves using environmentally friendly and biocompatible materials, such as plant extracts or biological agents, to reduce silver ions and produce silver nanoparticles. This method is gaining popularity owing to its eco-friendliness and potential for biomedical applications. The green synthesis method can be summarized as follows [11, 12]:

a. **Selection of Bio-Reducer**: A plant extract rich in natural compounds (e.g., flavonoids, polyphenols) or a microorganism with reducing properties is chosen as the bio-reducer.
b. **Mixing with Silver Precursor**: The selected bio-reducer is mixed with a silver ion solution (e.g., silver nitrate) to initiate the process of reduction.
c. **Formation of AgNPs**: The bio-reducer reduces the ions of silver, causing the AgNPs formation.
d. **Characterization**: The resulting AgNPs are characterized to verify their size, shape, and stability.

The green synthesis method is advantageous as it eliminates the need for hazardous chemicals and offers the potential for biocompatible nanoparticles. However, the synthesis conditions and choice of bio-reducer may influence the properties of the resulting silver nanoparticles.

It's worth noting that there are several other methods to synthesize silver nanoparticles, such as physical methods (e.g., laser ablation, electron beam irradiation) and biological methods (e.g., biosynthesis using plant extracts, fungi, or bacteria). The option of synthesis method depends on the precise application requirements, scalability, and desired nanoparticle properties.

The most recent silver nanoparticles synthesis methods

Chemical Precipitation:

This method involves the controlled mixing of reactants to form nanoparticles. It is widely used due to its simplicity and scalability [13].

Sol-Gel Method:

This method involves the conversion of a precursor solution into a gel and subsequent drying to form nanoparticles. It is commonly used for the MO (Metal Oxides nanoparticles synthesis [8].

Hydrothermal Synthesis:

In this method, nanoparticles are crafted under conditions of elevated temperature and pressure, ensuring precise control over their size and morphology. [14].

Microwave-Assisted Synthesis:

Microwaves are used to heat the reaction mixture, resulting in rapid and efficient nanoparticle formation [15].

Green Synthesis:

This approach focuses on using environmentally friendly and sustainable methods, such as plant extracts or biological processes, to produce nanoparticles [11].

Electrochemical Synthesis: Nanoparticles can be electrochemically synthesized by applying a voltage to the reactants [16].

Aerosol Methods:

Nanoparticles can be produced by spraying reactants into a high-temperature environment, leading to their condensation and formation [17].

Applications of Silver Nanoparticles

Silver nanoparticles (AgNPs) find diverse applications in various fields thanks to their distinctive attributes, such as small size, expansive surface area, and exceptional antimicrobial and catalytic properties. Some notable applications of silver nanoparticles encompass [5-9].

Antimicrobial Agents:

Silver nanoparticles are recognized for their potent antimicrobial characteristics. In medical settings, like wound dressings and coatings for medical devices, they are employed to deter infections and facilitate the healing process.

Biomedical Applications:

AgNPs show promise in drug delivery systems, imaging agents, and diagnostic tools in biomedicine field. The small size and surface properties make them suitable for targeted drug delivery to specific cells or tissues.

Water Treatment:

Silver nanoparticles are effective in removing contaminants and pathogens from water due to their antimicrobial properties. They can be used in water purification processes to ensure safe drinking water.

Textiles and Clothing:

Incorporating silver nanoparticles into fabrics imparts antimicrobial properties, leading to odor control and reduced bacterial growth. This application is especially useful in sportswear, medical textiles, and other hygiene-sensitive products [18].

Electronics:

Silver nanoparticles find applications in the electronics industry as conductive inks, coatings, and adhesives. They are used to create conductive traces on flexible circuits and as fillers in printable electronics [8].

Catalysis:

Silver nanoparticles exhibit excellent catalytic activity, making them useful in various chemical reactions and industrial processes, such as catalytic converters, sensors, and environmental applications [19].

Food Packaging:

Silver nanoparticles can be incorporated into food packaging materials to extend the shelf life of perishable products by inhibiting bacterial and fungal growth [20].

Cosmetics:

Silver nanoparticles are used in cosmetic formulations for their antibacterial properties. They can be found in creams, lotions, and personal care products [21].

Photonic Applications:

Due to their size-dependent optical properties, silver nanoparticles find use in photonic applications like surface-enhanced Raman spectroscopy (SERS), where they greatly amplify the Raman signals of analytes, aiding in sensitive detection.

Importance of Silver Nanoparticles [6-12]

Silver nanoparticles are important to researchers for several reasons, mostly by reason of their exceptional properties and flexible applications. Some key reasons why researchers find silver nanoparticles important are:

Antimicrobial Properties:

Silver nanoparticles exhibit strong antimicrobial properties, being effective against a broad bacteria spectrum, fungi and. This makes them valuable for developing new antimicrobial agents, medical devices, wound dressings, and water purification technologies.

Drug Delivery Systems:

The compact size and expansive surface area of silver nanoparticles render them fitting candidates for drug delivery systems. Researchers can functionalize the nanoparticles to encapsulate drugs and target specific cells or tissues, improving drug effectiveness while minimizing side effects.

Catalysis:

Silver nanoparticles possess excellent catalytic activity, this aspect captivates the attention of researchers in the realms of chemistry and materials science. They can be used as catalysts in various chemical reactions, enhancing reaction rates and selectivity.

Nanotechnology and Nanomaterials Research:

As nanomaterials, silver nanoparticles serve as model systems for researchers to study the unique properties and behaviors of materials at the nanoscale. Their study contributes to advancements in nanotechnology, leading to innovations in various fields.

Sensors and Diagnostics:

Silver nanoparticles are utilized in the development of sensors and diagnostic tools due to their surface-enhanced Raman scattering (SERS) properties. This enables the precise and discerning detection of molecules and analyses, a critical capability in medical diagnostics and environmental monitoring.

Electronics and Photonics:

Researchers use silver nanoparticles in electronics for conductive inks, transparent conductive films, and other applications. Additionally, their plasmonic properties make them important in photonics for enhancing light-matter interactions [20, 21].

Environmental Applications:

Research on silver nanoparticles extends to environmental science and engineering, where they are studied for their potential in wastewater treatment, pollutant removal, and environmental remediation [22].

Material Science and Engineering:

The study of silver nanoparticles contributes to a deeper understanding of nanomaterial synthesis, characterization, and manipulation. This knowledge aids in advancing material science and engineering as a whole.

Sustainable Technologies:

Scientists are investigating eco-friendly and sustainable approaches in the green synthesis of silver nanoparticles. This contributes to the development of greener and more sustainable technologies.

Last Ten Years of Silver Nanoparticles in Iraq

Sulaiman *et al*., 2013 [23], did a study aimed at preparing silver nanoparticles using green synthesis by which Eucalyptus chapmaniana leaves extract was used and AgNPs. their antimicrobial properties against various pathogenic bacteria and yeast were evaluated and also the toxicity was tested on the human acute promyelocytic leukemia (HL-60) cell line, however, the study found that the AgNPs obtained from *E. chapmaniana* leaves demonstrate excellent stability and exhibit antimicrobial and anticancer properties.

In 2014 Muhsin and Hachim [24], who work at Basrah University, did a study that aimed to produce silver nanoparticles through the biosynthesis method, employing the fungus Nigrosporasphaerica, isolated from soil samples. The researchers aim to assess the efficacy of these nanoparticles against five strains of bacteria that pose a threat to human health, namely Escherichia coli, Pseudomonas aeruginosa, Proteus mirabilis, Staphylococcus aureus, AND Salmonella typhi, all the assessment will be carried out using the disc diffusion method. The research revealed a significant improvement in antibacterial activity when AgNPs were applied in conjunction with Gentamycin, as indicated by a noteworthy increase in fold area. Silver nanoparticles synthesized from the fungus N. sphaerica exhibit considerable potential as a secure and efficient choice for medical therapy, owing to their broad-spectrum effectiveness against pathogenic bacteria.

In 2015, a study conducted at the University of Baghdad, College of Education for Pure Sciences, Ibn Al-Haithm by Al-Kalifawi and colleagues [25], aimed to achieve green synthesis of silver nanoparticles using onion (Allium cepa) extract as both the reducing and capping agent. The research demonstrated that silver nanoparticles, synthesized with onion extracts, exhibited robust antibacterial activity against various bacterial strains, including Escherichia coli, Proteus mirabilis, Klebsiella oxytoca, Streptococcus sp., Enterobacter cloacae, Bacillus sp., Pseudomonas aeruginosa, and Staphylococcus aureus. These strains were sourced from the diagnostic laboratory of Al-Numan Hospital in Baghdad. The results suggest that silver nanoparticles produced with onion extracts hold potential as an effective therapeutic agent for treating microbial infections in humans.

Nasir *et al*., 2016 [26], carried out another study in University of Baghdad. The research has effectively devised a swift, environmentally friendly, and user-friendly approach for synthesizing stable silver nanoparticles (AgNPs) with an average diameter of 40 ± 5.0 nm. These nanoparticles take on a spherical form and are created through the utilization of an aqueous solution containing Olive tree (Olea europaea) leaf extract, acting as both the reducing and capping agent, in combination with D-sorbitol. The reaction is conducted with a silver nitrate concentration of 10^{-3}M, and we investigated the influence of temperature by stirring at both room temperature (25°C) and 60°C. The confirmation of AgNPs synthesis was achieved through the observation of a color change to dark brown-grey. To thoroughly characterize the synthesized AgNPs, they employed various techniques, including FTIR, UV-Visible spectroscopy, AFM, and SEM.

In 2017, a separate study was conducted at the Faculty of Medicine, University of Al-Qadisiyah, Iraq, by Dakhil 2017 [27]. The research focused on the biosynthesis of silver nanoparticles (AgNPs) using a Lactobacillus mixture and subsequently evaluated their antioxidant activity. The study provided evidence of the beneficial role of Lactobacillus, showing an increase in antioxidant activity when combined with AgNPs. Moreover, Lactobacillus exhibited an ameliorative function against the adverse effects of high doses of AgNPs. The present study provided evidence of the beneficial role of Lactobacillus, showing an increase in antioxidant activity when combined with AgNPs. Moreover, Lactobacillus exhibited an ameliorative function against the adverse effects of high doses of AgNPs.

In 2018, a study was conducted in Iraq through collaboration between University of Sulaimani and Tikrit University by Hamzah *et al*., 2018 [28], the study outlines the synthesis of (AgNPs) using Fusarium mangiferae. Additionally, it investigates the antibiofilm activity of these nanoparticles against Staphylococcus aureus and discovered the cytotoxicity mammalian normal cell lines. This study provides evidence of the effectiveness of AgNPs as an antibiofilm agent against S. aureus, indicating their potential as an alternative to antibiotics. However, it is crucial to highlight that AgNPs also exhibited cytotoxic effects on mammalian normal cell lines.

A study in 2019 was conducted also in Iraq by Alabdul Aziz *et al*., 2019 [29], the work present a cost-effective, environmentally friendly, and previously unreported approach for synthesizing silver nanoparticles, the technique involves utilizing the Lawsoniainermis leaf concentrate extract that was used as a green reducing agent. The findings demonstrated that the hybrid nanosilver-organic particles exhibited a significant enhancement in antibacterial efficacy for both initial compounds, it also demonstrate a remarkable effectiveness against gram-positive bacteria.

Saleh and Najim 2020 [30], did a study that successfully synthesized (AgNPs) using silver nitrate and extracts from four distinct latex-producing plants belonging to two families (Euphorbiaceae and Moraceae). The research concluded that this nanoparticle source holds significant potential as an advantageous industrial project, aiming to discover new, safe, and economical alternatives to antibiotics.

A review study was carried out in 2020 by Salleh *et al*., 2020 [31], the review discusses the applications and constraints of AgNPs, including their potential cytotoxicity to both humans and the environment. Through an analysis of the literature search, as well as the various properties of AgNPs that are concerning their antiviral and antibacterial effects that depends on the synthesis processes, and the morphological structure of AgNPs.

Talabani *et al*., 2021 [32], synthesized AgNps using the leaves extract of petroselinumcrispum which commonly known as parsley, as a non-hazardous alternative for capping, reducing, and stabilizing agent to produce Ag NPs. The study concluded that using parsley leaf extract, a straightforward, rapid, safe, and one-pot green method was employed to synthesize high-purity, thermally stable, monodisperse, and spherical Ag NPs. Various characterization techniques were then employed to examine the biosynthesized Ag NPs, focusing on their crystal structure, morphology, stability, purity, thermal and optical properties. It was also observed that the combination of flavonoid complex and polyphenols and demonstrates superior reducing and capping properties compared to using flavonoids or polyphenols individually. As a result, this complex has the ability to produce monodisperse, spherical, and homogenous silver NPs. The investigation revealed that the biosynthesized Ag NPs released heat due to irradiation around 450nm, leading to the thermal decomposition of localized surface plasmon resonance. These findings are promising, demonstrating the potential of Ag NPs as a means to convert solar energy into thermal energy.

In 2022, Haider and Hussein [33], carried out a study concluded to assess the effectiveness of locally and biologically manufactured silver nanoparticles, produced by Aspergillus Niger, in inhibiting the production of aflatoxin B1 (AFB1). The findings demonstrated the efficacy of locally and biologically produced silver nanoparticles in reducing AFB1 levels during the maize grain storage experiment. Notably, treatments T0.8 and T0.6 were particularly effective, reducing AFB1 to 0.0, surpassing the results achieved by treatments T0.4 and T0.2.

Abbas *et al*., 2023 [34], in their study a successful fabrication of solid and hollow silver nanoparticles (Ag NPs) has been accomplished. The experimental results demonstrated that Solid Ag NPs exhibited significant bactericidal activity against isolated bacteria, proving to be particularly effective against both Gram-negative and Gram-positive bacteria. Furthermore, the antibacterial activity of the solid nanoparticles was observed to be dependent on both time and concentration.

Above are the articles that were published in the last 10 years, however, the current review cannot coverall the entire articles, but every year an article was selected randomly and was discussed.

Table 1: below shows another 10 articles that were published from 2018 to 2023-08-13

No.	Authors	Main findings
1.	Hassan Afandy *et al*., 2023 [35]	This study explores the use of green tea (GT) extract as a reducing agent in the synthesis of silver nanoparticles (Ag NPs) with a crystalline structure. The resulting silver nanoparticles (Ag NPs) demonstrated promising antimicrobial effects against both Gram-positive (GP) bacteria, specifically Brevibacteriumluteolum and Staphylococcus aureus, and Gram-negative (GN) bacteria, including Pseudomonas aeruginosa and Escherichia coli. The minimum inhibitory concentration (MIC) was found to be 6.4mg/mL for GN bacteria and 12.8mg/mL for GP bacteria. Overall, these findings suggest the potential application of AgNPs as effective antimicrobial agents.
2.	Jabir *et al*., 2021 [36]	In this study, silver nanoparticles were produced by utilizing A. muricata peel extract as a reducing agent, with the enhanced efficacy credited to the pharmaceutical activity of A. muricata. In conclusion, this study proposes that AgNPs hold significant potential as a therapy for diverse cancer types and as an alternative approach for inflammation prevention by bolstering autophagy.
3.	Faris *et al*., 2022 [37]	Silver nanoparticles (Ag NPs) have been utilized to produce heat and raise the temperature of water through solar radiation energy. Optimal plasmonic heating is achieved when the wavelength of the light source closely matches the plasmonic resonance wavelength of the Ag NPs. The assessment of existing patents underscores the significance of the realm involving the green synthesis of Ag NPs using plant extracts. This approach yields Ag NPs that are notably stable, safe, and efficacious. A noteworthy aspect of this patent lies in the ability to synthesize Ag NPs through a one-pot reaction devoid of external stabilizers and reducing agents, a feat not attainable with prevailing methodologies. Additionally, this study stands as an uncommon and distinct contribution, showcasing the remarkable efficacy of even a minute quantity of Ag NPs in significantly elevating water temperature.
4.	Taha *et al*., 2019 [38]	The study delved into the synthesis of silver nanoparticles and assessed their antioxidant, antimicrobial, and cytotoxic activities through an extracellular biosynthesis method employing Penicillium italicum, isolated from Iraqi lemon fruits. The potent bioactivity exhibited by the produced silver nanoparticles suggests their potential biomedical application as agents for antioxidative, antimicrobial, and cytotoxic purposes.
5.	Saeed *et al*., 2019 [39]	The aim of the study was to conduct a systematic review of research investigating the impact of nanoparticles on angiogenesis. The study found that Spherical shape emerged as the prevalent choice for studying the influence of nanoparticles on angiogenesis therapy. Nanoparticle size appears pivotal for angiogenic efficacy, with 20 nm being the preferred dimension. Gold nanoparticles hold considerable potential as antiangiogenic agents, and toxicity was modulated by dosage levels.
6.	Onyeaka *et al*., 2022 [40]	The utilization of nanomaterials in food science is examined, encompassing their benefits and drawbacks, along with the potential human health risks and methods for detecting nanocomponents.
7.	Mohsen *et al*., 2022 [41]	Trichophyton rubrum, a dermatophytic fungus, was employed in this study to synthesize silver nanoparticles, and it was found that The existence of AgNPs was verified through SEM analysis, which depicted their predominantly spherical shape and size of approximately 100nm. Additionally, the results indicated that the silver nanoparticles exhibited antifungal properties against both infections, with effectiveness varying based on concentration. Notably, at a concentration of 150 ppm of AgNPs, growth reduction was observed.
8.	Tomah *et al*., 2020 [42]	The researchers found that SEM and EDS analyses unveiled the direct interaction between nanoparticles and fungal cells, encompassing the contact, accumulation, production of lamellar fragments, and the creation of micropores or fissures on the fungal cell walls, particularly with AgNPs. These findings contribute to enhancing our comprehension of the mechanisms through which AgNPs function to counteract various fungal diseases.
9.	Taha *et al*., 2019 [43]	This study explored the synthesis of silver nanoparticles and examined their antioxidant, antimicrobial, and cytotoxic properties, achieved through extracellular biosynthesis utilizing Penicillium italicum, which was isolated from lemon fruits in Iraq. The robust bioactivity demonstrated by the produced silver nanoparticles suggests their potential application in biomedicine as agents with antioxidant, antimicrobial, and cytotoxic properties.
10.	Hamzah *et al*., 2018 [44]	The research delineates the synthesis of silver nanoparticles (AgNPs) through Fusarium mangiferae. The study encompasses the assessment of the nanoparticles' antibiofilm potential against Staphylococcus aureus as well as their cytotoxic effects on mammalian cell lines. Fusarium mangiferae is capable of producing well-dispersed nanoparticles. The findings from this investigation underscore the effectiveness of AgNPs in countering S. aureus biofilms, implying their potential as an antibiotic alternative. Additionally, it's important to note that AgNPs exhibited cytotoxic effects on mammalian cell lines. Further research is required to comprehensively evaluate the risk-benefit ratio associated with the utilization of AgNPs.

The optical properties of silver nanoparticles are truly striking. Their size-dependent optical behavior, referred to as localized surface plasmon resonance (LSPR), gives them a spectrum of vibrant colors spanning from yellows to reds. This characteristic makes them exceptionally suitable for various applications in optics, sensing, and imaging technologies. By leveraging this unique property, scientists have engineered sensitive biosensors capable of detecting even minute concentrations of biological analytes. This breakthrough has brought about a revolution in medical diagnostics and environmental monitoring. Silver nanoparticles symbolize the culmination of nanotechnology's potential and promise. With their distinctive blend of optical, electrical, and antimicrobial attributes, they stand as indispensable assets across various domains including healthcare and electronics. As exploration progresses and technology develops, the narrative of silver nanoparticles unfolds, offering the prospect of additional breakthroughs and revelations where nanoscience intersects with society [45-50].

CONCLUSIONS

- Silver nanoparticles (Ag NPs) hold significant potential in a variety of applications due to their exceptional properties and versatile nature.
- The green synthesis of Ag NPs using natural extracts, such as parsley leaf extract, offers a safe, rapid, and environmentally friendly alternative.
- The biosynthesized Ag NPs exhibit high purity, thermal stability, and a monodisperse spherical shape, making them ideal for various applications.
- Furthermore, the combination of polyphenols and flavonoid complex has been found to enhance the reducing and capping properties of Ag NPs, resulting in the production of homogenous, spherical, and monodisperse nanoparticles.
- The plasmonic effect of the biosynthesized Ag NPs was investigated, revealing their ability to convert solar energy into thermal energy efficiently. This characteristic makes them promising candidates for solar energy conversion and water heating applications. Moreover, Ag NPs have shown effectiveness in inhibiting the production of aflatoxin B1 (AFB1) by A. flavus, suggesting their potential in food safety and preservation.
- In bactericidal applications, Solid Ag NPs exhibited remarkable antibacterial activity against various bacteria, showing time and concentration-dependent effects.
- Additionally, the hollow AgNPs demonstrated potential in specific applications, presenting opportunities for further research and development.

The overall findings highlight the promising and diverse capabilities of silver nanoparticles, making them valuable materials for a wide range of technological, biomedical, and environmental applications. However, further research is needed to fully understand and optimize their properties, safety, and potential limitations in different contexts.

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