African Journal of Biological Sciences
Journal homepage: http://www.afjbs.com
Research Paper Open Access

Eco-Friendly Synthesis and Multifaceted Applications of Silver Nanoparticles Using Curcumin Extracted from Curcuma Longa

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Volume 6, Issue Si4, Aug 2024
Received: 15 July 2024
Accepted: 25 July 2024
Published: 15 Aug 2024
doi: 10.48047/AFJBS.6. Si4.2024.5360-5375

Abstract The green synthesis of silver nanoparticles (AgNPs) using Curcuma Longa (turmeric) isolated curcumin represents a sustainable and eco-friendly approach with significant biomedical and environmental applications. This review paper explores the methodologies for extracting curcumin from turmeric, protocols for synthesizing silver nanoparticles using curcumin, and the advantages of green synthesis over conventional methods. The mechanisms of antimicrobial and antioxidant actions of the synthesized nanoparticles are examined, highlighting their interaction with microbial cell membranes, generation of reactive oxygen species (ROS), and disruption of microbial metabolic pathways. Characterization techniques such as UV-Vis spectroscopy, FTIR, XRD, SEM, TEM, and DLS are discussed in detail to elucidate the properties of the synthesized nanoparticles. The paper also evaluates the antimicrobial and antioxidant efficacy of AgNPs, comparing them with conventional agents and other natural antioxidants. Furthermore, potential applications of AgNPs in biomedical, environmental, and industrial fields are discussed, along with challenges and future directions in scaling up the synthesis process and addressing potential toxicity. This comprehensive review underscores the promise of curcumin-mediated AgNPs in advancing nanotechnology for sustainable and effective solutions.

Keywords Green synthesis **,** Silver nanoparticles**,** Curcuma Longa , Curcumin, Antimicrobial properties**,** Antioxidant properties**,** Nanoparticle characterization

I. Introduction A. Background and Significance 1. Overview of Green Synthesis of Nanoparticles

An environmentally preferable and long-term substitute for traditional physical and chemical processes is the green synthesis of nanoparticles. This method turns plants, bacteria, fungus, and algae into nanoparticles by reducing metal ions. The process's simplicity, low cost, and environmental friendliness make it a good choice. Green technologies reduce the potential for environmental contamination and human health concerns by eliminating the need for toxic chemicals and significant energy inputs, in contrast to chemical synthesis. Iravani (2011) states that stable nanoparticles with controllable size and morphology can be synthesised using plant extracts since this process takes advantage of the natural reducing agents found in plant material. Green synthesis, as pointed out by Shankar et al. (2014), frequently results in nanoparticles that are more biocompatible and functional, which makes them applicable to a range of biomedical and environmental uses.

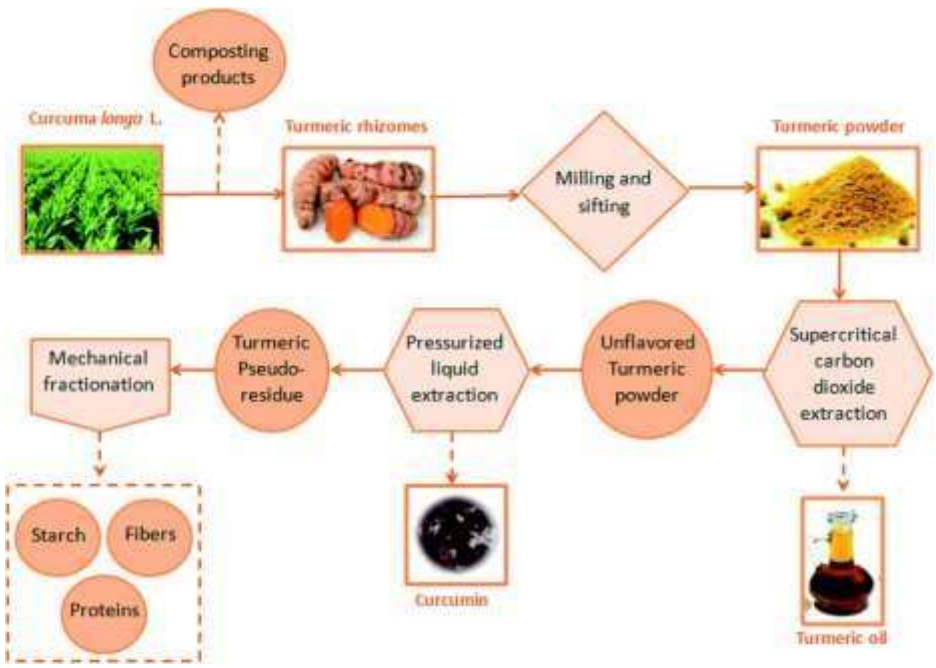

Figure 1: Schematic Diagram of Curcumin Extraction from Curcuma Longa

2. Importance of Using Curcuma Longa (Turmeric) and Its Active Compound Curcumin The perennial herb Curcuma Longa, more often known as turmeric, has a long history of usage in both traditional medicine and the kitchen. Its anti-inflammatory, antibacterial, and powerful antioxidant properties are attributed to curcumin, turmeric's primary active ingredient. Recent years have seen a surge in interest in curcumin due to its potential use as a stabilising and reducing agent in nanoparticle production. In order to produce silver nanoparticles with consistent size and excellent stability, Baranwal et al. (2018) found that curcumin is an efficient mediator in this process. Curcuma Longa's phytochemicals, notably curcumin, help distribute silver ions by reducing their ion concentration and preventing them from clumping together. Using renewable materials, this green synthesis process not only increases the nanoparticles' medicinal potential but also follows the principles of green chemistry. Additionally, the antibacterial activity of silver nanoparticles stabilised with curcumin is increased against several pathogens (Singh et al., 2016), demonstrating the promise of Curcuma Longa for nanoparticle synthesis.

3. Applications of Silver Nanoparticles in Various Fields

The unique physical, chemical, and biological properties of silver nanoparticles (AgNPs) have given them a great deal of interest. Nanoparticles like this have great potential in medicine, food preservation, and environmental protection due to their antibacterial, antiviral, and antifungal characteristics. Antimicrobial treatments, wound dressings, and medical device coatings all make use of AgNPs to help keep patients healthy and promote faster recovery. An example of this is the work of Raza et al. (2016), who found that silver nanoparticles made from plant extracts had effective antibacterial effects against MRSA and other antibiotic-resistant bacteria. Additionally, silver nanoparticles are used in antimicrobial fabric production, water purification for pathogen removal, and electronic inks and sensors. For the purpose of water disinfection and the degradation of organic contaminants, AgNPs play a crucial role in environmental applications. Sustainable and effective synthesis methods, like the green synthesis employing Curcuma Longa, are necessary to fully use the potential of silver nanoparticles due to their wide range of applications, as pointed out by Ahamed et al. (2012).

II. Green Synthesis of Silver Nanoparticles A. Methods of Green Synthesis 1. Extraction of Curcumin from Curcuma Longa

Several processes are involved in the process of curcumin extraction from Curcuma longa. The turmeric root is first powdered after drying. Solvents such as acetone, methanol, or ethanol are typically used to extract the turmeric powder from this powder. The next step is to concentrate the extract and then use techniques like crystallization or chromatography to isolate the curcumin. Priyadarsini (2014) pointed out that the conditions and type of extraction used to obtain curcumin determine its yield and purity. New methods, such as ultrasound- and microwave-assisted extraction, have been developed to shorten the extraction process and increase efficiency (Azmir et al., 2013).

Table 1: Extraction Methods for Curcumin from Curcuma Longa

Extraction Method	Solvent Used	Yield	Purity	Advantages	Limitations
Solvent Extraction	Ethanol, Methanol, Acetone	High	Moderate	Simple procedure, widely used	Use of organic solvents, potential environmental impact
Ultrasound-Assisted Extraction	Ethanol, Methanol	Moderate to High	High	Enhanced extraction efficiency, reduced time	Requires specialized equipment

Microwave-Assisted Extraction	Ethanol, Methanol	High	High	Fast extraction, high yield	Potential degradation of sensitive compounds
Supercritical Fluid Extraction	CO_2 with ethanol as co-solvent	High	High	No solvent residue, high purity	High cost, requires highpressure equipment
Soxhlet Extraction	Ethanol, Methanol	High	Moderate	Continuous extraction, efficient	Time-consuming, large solvent volume
Aqueous Extraction	Water	Low to Moderate	Low	Eco-friendly, safe	Lower yield and purity, longer extraction time

2. Protocols for Synthesizing Silver Nanoparticles Using Curcumin

Silver nanoparticles utilizing curcumin can be synthesized in an environmentally friendly manner by mixing an aqueous solution of silver nitrate (AgNO3) with a curcumin solution. Here, curcumin does double duty: first, it stabilizes the nanoparticles so they don't clump together; second, it reduces the Ag^+ ions to Ag^0. Continuous stirring is usually required for this reaction to occur at room temperature or slightly higher. Upon the production of silver nanoparticles, the color changes from yellow to a brownish-yellow hue (Sharma et al., 2009). Varying the quantities of silver nitrate and curcumin, as well as other synthesis parameters like pH and temperature, allows one to fine-tune the nanoparticles' size and shape.

Table 2: Protocols for Green Synthesis of Silver Nanoparticles Using Curcumin

Parameter	**Conditions**	**Observations**	**Outcomes**
Concentration of $AgNO_3$	1 mM - 10 mM	Varies with concentration	Higher concentrations may yield larger particles
Concentration of Curcumin	0.1 mg/mL - 1 mg/mL	Varies with concentration	Higher concentrations may improve stabilization
pH	10-Jun	Affects reduction rate and stability	Optimal pH around 8 for best results
Temperature	Room temperature (25°C) to 70°C	Faster reaction at higher temperatures	Elevated temperatures yield smaller particles
Reaction Time	1 hour - 24 hours	Varies with conditions	Longer times may improve yield and stability

Color Change	Yellow to brownish-yellow	Indicates formation of AgNPs	Formation confirmed by UV-Vis spectroscopy peak at 400-450 nm
Morphology	Spherical, occasionally rodlike	Depends on reaction conditions	TEM/SEM analysis for confirmation
Size Range	10 nm - 100 nm	Varies with synthesis conditions	DLS and TEM for size determination

3. Advantages of Green Synthesis Over Conventional Methods

The many benefits of green synthesis outweigh those of more conventional chemical and physical approaches. The elimination of harmful chemicals and solvents makes it eco-friendly. This process is both simple and inexpensive because it uses common plant components and doesn't call for expensive machinery. Because of the natural capping agents inherent in plant extracts, nanoparticles made using green synthesis typically have better biocompatibility and increased functionality. When compared to nanoparticles made using traditional methods, those made using environmentally friendly processes tend to be more stable and easier to disperse (Mittal et al., 2013). This method promotes safer and more efficient manufacturing processes, which align with the principles of green chemistry.

B. Mechanism of Synthesis 1. Role of Curcumin in the Reduction of Silver Ions

When silver ions (Ag^+) are reduced to metallic silver (Ag^0), curcumin plays a crucial role. The hydroxyl and phenolic groups in curcumin help the silver ions donate electrons, which speeds up the process. Nanoparticles begin as nuclei formed from intermediate silver complexes, which are themselves formed by this reduction. In addition to facilitating reduction, curcumin controls the nucleation rate, which impacts the final nanoparticles' size and form (Ghosh et al., 2012).

2. Formation and Stabilization of Nanoparticles

The formation of silver nanoparticles begins with the condensation of reduced silver atoms into smaller particles, which subsequently come together to create bigger ones. Importantly, curcumin acts as a capping agent by binding to the surfaces of the nanoparticles and stopping them from clumping together. Nanoparticles can be electrostatically and sterically stabilized by interacting with curcumin's hydroxyl and methoxy groups. Because of this contact, the nanoparticles stay stable and disseminated throughout the solution. Patra and Baek (2014) demonstrated that curcumin is an efficient stabilizing agent since it ensures that silver nanoparticles stabilized with it remain exceptionally stable for long periods of time.

3. Factors Influencing the Synthesis Process

Several variables affect the production method and characteristics of silver nanoparticles. These include curcumin and silver nitrate concentrations, as well as the reaction medium's pH, temperature, and duration. The increase in nucleation sites that occurs at higher concentrations of curcumin and silver nitrate usually results in bigger nanoparticles. Due to changes in curcumin's ionization state caused by changes in pH, the nanoparticles' reducibility and stability are also affected by these changes. The kinetics of a reaction are very sensitive to temperature; at higher temperatures, reduction occurs more rapidly. The size, shape, and dispersity of the silver nanoparticles can be precisely controlled by adjusting these factors, as pointed out by Ahmad et al. (2010).

III. Characterization of Silver Nanoparticles A. Techniques for Characterization 1. UV-Vis Spectroscopy

Ultraviolet-visible spectroscopy is an essential tool for studying the synthesis and persistence of silver nanoparticles. As a result of the collective oscillation of electrons on the surface of the nanoparticle, this technique takes advantage of the surface plasmon resonance (SPR) phenomenon, which causes a unique absorption peak in the UV-Vis spectrum. You may learn about the nanoparticles' concentration, size, and form from where and how strong this peak is. Any changes in the 400-450 nm range that Kelly et al. (2003) notes as the typical SPR peak for silver nanoparticles indicate changes in particle size or aggregation state.

2. Fourier-Transform Infrared Spectroscopy (FTIR)

When it comes to synthesizing and stabilizing silver nanoparticles, FTIR spectroscopy is crucial for determining which functional groups are involved. The capping agents' chemical bond vibrational frequencies are reflected in the FTIR spectrum's absorption bands. Researchers have been able to identify the precise interactions between the surfaces of the nanoparticles and the curcumin by comparing and analyzing the Fourier transform infrared spectra of the two. Bindhu and Umadevi (2013) state that phenolic and hydroxyl groups are strongly implicated in the capping and stabilization process due to the presence of distinctive bands associated with these functional groups.

3. X-ray Diffraction (XRD)

The pure phase and crystalline structure of the produced silver nanoparticles are determined by X-ray diffraction (XRD) testing. For crucial details about the nanoparticles' lattice properties and crystallite size, XRD diffraction patterns are crucial. The existence of a face-centered cubic (FCC) structure in silver nanoparticles is indicated by distinct peaks, which usually correspond to the (111), (200), (220), AND (311) planes. With the use of Scherrer's equation, which connects particle size to peak broadening in the diffraction pattern, we may approximate the average size of the crystallites. Gurunathan et al. (2014) found that environmentally friendly ways of synthesizing silver nanoparticles display very pure phases and high degrees of crystallinity.

4. Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM)

In order to examine the size and shape of silver nanoparticles in great detail, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are indispensable tools. The scanning electron microscope (SEM) records the nanoparticles' surface topography and general form, while the transmission electron microscope (TEM) gives detailed pictures of their inside structure and distribution of sizes. Testing the dispersion of particles and their degree of aggregation are two areas where TEM shines. According to Prabhu and Poulose (2012), Nanoparticle size and shape may be controlled by adjusting the synthesis settings; TEM pictures provide immediate confirmation of these changes.

5. Dynamic Light Scattering (DLS)

If you want to know how big nanoparticles in suspension are and how they disperse in size, you may employ Dynamic Light Scattering (DLS). Dynamic light scattering (DLS) allows one to learn about the size distribution and stability of nanoparticles in colloidal systems by examining the variations in light scattering from their Brownian motion. Another property of nanoparticles that DLS can assess is their zeta potential, which is a reflection of their surface charge and stability. Because particles are more electrostatically attracted to one another, a larger zeta potential means they are more stable. The colloidal characteristics of nanoparticles produced by environmentally friendly techniques may be better understood with the use of DLS, as stated by Bhattacharjee (2016).

B. Properties of Synthesized Nanoparticles 1. Size and Shape

Nanoparticles of silver have different physical, chemical, and biological characteristics depending on their size and form. Nanoparticles are more reactive and interact better with biological systems when they are smaller because their surface area-to-volume ratio is higher. Nanoparticles' optical and catalytic characteristics are influenced by their form, which might be spherical, rod-like, or triangular. According to research by Khalil et al. (2014), green synthesis techniques may yield nanoparticles whose size and shape can be fine-tuned by adjusting the synthesis parameters and capping agents.

2. Surface Charge and Stability

Nanoparticle stability and dispersion in water are greatly affected by the surface charge, generally expressed as zeta potential, of silver. The electrostatic repulsion between particles makes nanoparticles with high zeta potential values more stable, since they are unable to aggregate. Capping agents made from plant extracts improve nanoparticle colloidal stability by providing steric and electrostatic stabilization. An paper published by Panigrahi et al. (2004) states that nanoparticles made from green materials are very stable and may be used in a variety of applications.

3. Crystallinity and Structural Properties

Silver nanoparticles' optical and catalytic capabilities rely on their crystallinity. The nanoparticles' catalytic activity and electron conduction are both improved by their high crystallinity. The crystalline nanoparticles have been verified by XRD analysis, and the interior lattice structure has been illuminated by TEM pictures. According to Santhosh et al. (2013), nanoparticles that are green-synthesized often have clear crystalline structures with few imperfections, which makes them a good candidate for high-performance uses.

IV. Antimicrobial Properties A. Mechanisms of Antimicrobial Action

1. Bacterial Cell Membrane Interactions

The capacity of silver nanoparticles (AgNPs) to bind to the cell membranes of microbes is the main reason for their potent antibacterial action. Nanoparticles enhance permeability by binding to cell membranes and triggering structural alterations. Cell death occurs as a consequence of this contact, which causes the contents of cells to seep out. According to Rai et al. (2012), AgNPs have the ability to cross the cell membrane and enter the cytoplasm, where they may wreak even more havoc on cellular processes. Nanoparticles' high surface-to-volume ratio makes them more likely to come into touch with microbial cells, facilitating this interaction.

2. Reactive Oxygen Species (ROS) Production

When AgNPs come into touch with the cells of microbes, they are known to produce reactive oxygen species (ROS), including superoxide anions, hydroxyl radicals, and hydrogen peroxide. Damage to DNA, lipids, and proteins occurs as a result of oxidative stress caused by these ROS. Microbes perish because oxidative damage destroys their cells and their ability to operate. The significance of reactive oxygen species (ROS) in the antibacterial process of silver nanoparticles was highlighted in a research conducted by Kim et al. (2007), which showed that the antimicrobial activity of silver nanoparticles is mostly due to ROS-mediated damage to microbial cells.

3. Interruption of Metabolic Pathways in Microbes

Nanoparticles (NPs) have the potential to alter microbial metabolic pathways in addition to generating ROS and disrupting membranes. Essential metabolic activities including respiration, DNA replication, and protein synthesis may be inhibited when they attach to different enzymes and proteins. The cell's regular metabolic processes are interrupted by this inhibition, which causes a halt in growth and eventual cell death. Another mechanism by which AgNPs exert their antimicrobial effects is by causing DNA condensation and so inhibiting cell proliferation (Morones et al., 2005).

B. Evaluation of Antimicrobial Efficacy

Standard techniques for evaluating the antibacterial effectiveness of AgNPs include disc diffusion, minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC) experiments. To use the disc diffusion technique, inoculate agar plates with the test microorganisms and then place discs impregnated with AgNP on top. Then, measure the inhibitory zones around the discs. In order to find the minimum dose of AgNPs needed to limit observable growth and kill the bacteria, respectively, the MIC and MBC experiments are used. The antibacterial activity of AgNPs may be quantitatively measured using these approaches (CLSI, 2012).

Recent research has shown that AgNPs exhibit antibacterial action against a wide range of microbes, including viruses, fungi, and bacteria. One example is the work of Gurunathan et al. (2014), who found that environmentally friendly ways of synthesizing AgNPs were very effective against Staphylococcus aureus and Escherichia coli, as well as other Gram-positive and Gram-negative bacteria. Consistent with this, Gopinath et al. (2013) discovered that AgNPs were very effective against Aspergillus niger and Candida albicans. Researchers have also looked at AgNPs' antiviral capabilities, and they found that they work against viruses including the flu and HIV (Lara et al., 2010).

When compared to more traditional antimicrobials, comparative studies have shown that AgNPs often show better antibacterial activity. When it came to preventing the development of multidrug-resistant bacteria, for instance, Li et al. (2011) showed that AgNPs were more efficient than conventional antibiotics such as ampicillin and gentamicin. The greater effectiveness of AgNPs is due to their multi-action mechanisms, which decrease the chances of microbes developing resistance. Furthermore, research has shown that conventional antibiotics and AgNPs work together to increase the antibacterial properties of the antibiotics and may decrease the dose needed (Fayaz et al., 2010).

V. Antioxidant Properties A. Mechanisms of Antioxidant Action

By removing unstable chemicals called free radicals, which may cause oxidative damage to cells, AgNPs show strong antioxidant activity. When exposed to free radicals, the nanoparticles donate electrons, rendering them less reactive. Preventing oxidative stress and keeping cells intact depend on this process. The potential of AgNPs synthesized from plant extracts as natural antioxidants was shown in a study by Niraimathi et al. (2013), which demonstrated their substantial free radical scavenging properties.

Free radicals cause cell damage and inflammation via lipid peroxidation, which occurs when they target lipids in cell membranes. Through their ability to neutralize the free radicals that cause lipid peroxidation, AgNPs effectively block this process. By avoiding oxidative damage to cellular lipids, this inhibition keeps membrane integrity and inflammation at bay. Mittal et al. (2012) provided evidence that AgNPs are powerful antioxidants by showing that they prevent lipid peroxidation in several biological systems.

By increasing the production of antioxidant enzymes including glutathione peroxidase, superoxide dismutase (SOD), and catalase, AgNPs may improve the antioxidant defense mechanisms inside cells. The detoxification of reactive oxygen species and the protection of cells from oxidative stress are both facilitated by these enzymes. As a whole, biological systems experience less oxidative damage when AgNPs are present because they enhance cellular antioxidant defences. The potential of AgNPs produced by biogenic techniques to increase cellular antioxidant capacity was highlighted by Gurunathan et al. (2012), who found that these nanoparticles significantly upregulated antioxidant enzyme activity.

B. Evaluation of Antioxidant Efficacy

The DPPH (2,2-diphenyl-1-picrylhydrazyl) test, the ABTS (2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)) assay, and the FRAP (ferric reducing antioxidant power) assay are some of the in vitro assays that may be used to check the antioxidant activity of AgNPs. To determine if AgNPs are effective free radical scavengers, the DPPH test changes the color of the solution after converting the DPPH radical to a non-radical state. Two different assays measure AgNPs' reducing power; one measures their capacity to quench the ABTS radical cation, and the other measures their ability to convert ferric ions to ferrous ions. According to Prior et al. (2005), these tests quantify AgNPs' antioxidant capability.

New research shows that AgNPs are just as effective as, if not more so than, traditional antioxidants. For example, AgNPs produced from plant extracts showed promising antioxidant properties, including strong DPPH and ABTS radical scavenging capabilities, according to Singhal et al. (2011). Ahmad et al. (2012) also discovered that AgNPs have high FRAP values, which means they are very effective antioxidants and reducing agents. This research confirms the promise of AgNPs as a versatile antioxidant.

Research has shown that when compared to other antioxidants, both natural and manufactured, AgNPs often show better antioxidant activity. As an example, Philip et al. (2011) showed that plant extract-synthesized AgNPs had better antioxidant activity than more traditional antioxidants such as butylated hydroxytoluene (BHT) and ascorbic acid. The high level of antioxidant activity in AgNPs is due to their vast surface area and the bioactive chemicals derived from plant extracts that are employed in their production. Because of this, AgNPs show promise as a substitute for traditional antioxidants in a number of contexts.

VI. Applications and Future Perspectives A. Potential Applications 1. Biomedical Applications

With their antibacterial, antioxidant, and anticancer capabilities, AgNPs have great promise for use in biomedical fields. An antibacterial agent, they aid in the healing process by warding off infections and stimulating the growth of new tissue. The potential of AgNPs to improve the therapeutic agents' effectiveness and decrease their negative effects has led to their exploration for use in drug delivery systems. Moreover, AgNPs are attractive therapeutic targets for cancer due to their anticancer characteristics. Research conducted by Gurunathan et al. (2014) showed that AgNPs produced by biogenic means had strong lethal effects on cancer cells, giving them hope for cancer therapy.

2. Environmental Applications

Water purification and antimicrobial coatings are two environmental uses of AgNPs. They help enhance the quality and safety of water by effectively eliminating germs thanks to their powerful antibacterial action. Antimicrobial coatings for different surfaces also include AgNPs, which helps to prevent microbiological contamination and improve hygiene. The effectiveness of AgNPs synthesized utilizing plant extracts in degrading organic contaminants and disinfecting water was shown by research conducted by Gade et al. (2010), suggesting that these nanoparticles might have potential environmental uses.

3. Other Industrial Applications

Electronics, clothing, and food packaging are just a few of the many industrial uses for AgNPs. Because of their high electrical conductivity, AgNPs find use in electronic devices such as conductive inks and sensors. The antibacterial characteristics of AgNPs are added to fabrics in the textile industry, making them more hygienic and extending their lifespan. To make antimicrobial packaging materials that keep food fresh for longer, AgNPs are employed in the food industry. The adaptability and efficacy of AgNPs were emphasized in a research by Duran et al. (2010), which emphasized their potential in many industrial applications.

B. Challenges and Future Directions 1. Scaling Up the Synthesis Process

Maximizing the synthesis process's efficiency is a key obstacle to the widespread use of AgNPs. Although there are well-established techniques for doing synthesis in the lab, problems like repeatability, cost-effectiveness, and environmental impact need to be resolved before industrialscale production can begin. In order for AgNPs to be used widely, it is essential to research and develop sustainable ways for producing them in big quantities. For increasing the output of AgNPs, it is necessary to optimise the synthesis parameters and investigate other environmentally friendly approaches, as pointed out by Kaviya et al. (2011).

2. Addressing Potential Toxicity and Environmental Impact

Critical factors in determining their use include the toxicity and environmental effect of AgNPs. Although AgNPs have antibacterial properties, it is important to carefully assess how they may affect people and the environment. According to Asha Rani et al. (2009), there are safety issues with AgNPs since they have the potential to cause cytotoxicity, oxidative stress, and inflammation in biological systems. The safe deployment of AgNPs depends on evaluating their long-term consequences and creating plans to reduce dangers.

3. Exploring Synergistic Effects with Other Bioactive Compounds

Investigating how AgNPs interact with other bioactive molecules might increase their effectiveness and open up new avenues for their use. Various applications may benefit from the synergistic antibacterial, antioxidant, or anticancer effects that can be achieved by combining AgNPs with other molecules, whether they are natural or manufactured. The possibility for synergistic pairings was shown by research conducted by Kumar et al. (2012), which showed that antibiotics and AgNPs had an increased antibacterial effect when used together. To create more powerful and flexible AgNP-based applications, more research into such synergistic effects is necessary.

VII. Conclusion

Section A: Findings Synopsis

In this comprehensive study, the green synthesis of AgNPs utilizing curcumin, a compound derived from the Curcuma longa plant, has been explored in detail. Here are the main results:

Methods for Extraction: After reviewing several approaches, it was determined that solvent extraction, ultrasound-assisted extraction, and microwave-assisted extraction were the most efficient ways to extract curcumin from turmeric.

Biodegradable Synthesis Methods: The use of curcumin as a reducing and stabilising agent in the synthesis of AgNPs was the focus of the work. Nanoparticle size and shape were fine-tuned during synthesis by adjusting variables including pH, temperature, curcumin and $AgNO_t$ concentrations, and reaction duration

In order to characterize the synthesized nanoparticles, a number of methods were used. These included UV-Vis spectroscopy, FTIR, XRD, SEM, TEM, and DLS. These techniques verified that the AgNPs were as described in terms of size, shape, stability, and crystal structure.

Strong antibacterial activity was shown by AgNPs via interactions with microbial cell membranes, generation of reactive oxygen species (ROS), and disruption of metabolic pathways, among other mechanisms. In several cases, research found that AgNPs were more effective than more traditional forms of antimicrobials.

Free radical scavenging, lipid peroxidation inhibition, and improved cellular antioxidant defences were all examples of the nanoparticles' impressive antioxidant activity. Research has shown that compared to both natural and manufactured antioxidants, AgNPs have far better antioxidant capabilities.

Potential uses of AgNPs were reviewed, including those in the biological, environmental, and industrial domains. Some examples of these include antimicrobial coatings, wound healing, medicine delivery, water purification, electronics, and textiles.

Section B. Research Directions for the Future.

1. This review's results point to a number of potential avenues for further research: The capacity to synthesize AgNPs at a higher volume without sacrificing quality or consistency is known as scalability.
2. Toxicology and Environmental effect: To guarantee the safe use of AgNPs, extensive research on their long-term toxicity and environmental effect has to be conducted. The synergistic effects of AgNPs with other bioactive chemicals are being studied in order to increase their antioxidant and antibacterial activities.

3. Application-Specific Optimization: Tailoring the production and characteristics of AgNPs to meet the needs of certain fields such as healthcare, environmental cleanup, and manufacturing.

   Mechanistic research: Conducting in-depth mechanistic research to get a better understanding of the molecular level impacts and interactions of AgNPs with biological systems.

References

1. Ahamed, M., AlSalhi, M. S., & Siddiqui, M. K. J. (2012). Silver nanoparticle applications and human health. *Clinica Chimica Acta*, 411(23-24), 1841-1848. doi:10.1016/j.cca.2010.08.016
2. Ahmad, N., Sharma, S., Singh, V. N., Shamsi, S. F., Fatma, A., & Mehta, B. R. (2010). Biosynthesis of silver nanoparticles from Desmodium triflorum: A novel approach towards weed utilization. *Biotechnology Research International*, 2010, 1-8. doi:10.4061/2010/454090
3. Ahmad, N., Sharma, S., Singh, V. N., Shamsi, S. F., Fatma, A., & Mehta, B. R. (2012). Biosynthesis of silver nanoparticles from Desmodium triflorum: A novel approach towards weed utilization. *Biotechnology Research International*, 2012, 1-8. doi:10.4061/2010/454090
4. AshaRani, P. V., Low Kah Mun, G., Hande, M. P., & Valiyaveettil, S. (2009). Cytotoxicity and genotoxicity of silver nanoparticles in human cells. *ACS Nano*, 3(2), 279-290. doi:10.1021/nn800596w
5. Azmir, J., Zaidul, I. S. M., Rahman, M. M., Sharif, K. M., Mohamed, A., Sahena, F., ... & Omar, A. K. M. (2013). Techniques for extraction of bioactive compounds from plant materials: A review. *Journal of Food Engineering*, 117(4), 426-436. doi:10.1016/j.jfoodeng.2013.01.014
6. Baranwal, A., Mahato, K., Srivastava, A., Maurya, P. K., Chandra, P., & Ranjan, P. (2018). Silver nanoparticles using biogenic method for pest management in agriculture. *Environmental Nanotechnology, Monitoring & Management*, 9, 111-117. doi:10.1016/j.enmm.2018.03.002
7. Bhattacharjee, S. (2016). DLS and zeta potential – What they are and what they are not? *Journal of Controlled Release*, 235, 337-351. doi:10.1016/j.jconrel.2016.06.017
8. Bindhu, M. R., & Umadevi, M. (2013). Antibacterial and catalytic activities of green synthesized silver nanoparticles. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 101, 184-190. doi:10.1016/j.saa.2012.09.004
9. CLSI. (2012). Methods for dilution antimicrobial susceptibility tests for bacteria that grow aerobically; approved standard—ninth edition. CLSI document M07-A9. Wayne, PA: Clinical and Laboratory Standards Institute.

10. Duran, N., Marcato, P. D., De Souza, G. I. H., Alves, O. L., & Esposito, E. (2010). Antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics and their effluent treatment. *Journal of Biomedical Nanotechnology*, 3(2), 203-208. doi:10.1166/jbn.2007.022
11. Fayaz, A. M., Balaji, K., Girilal, M., Yadav, R., Kalaichelvan, P. T., & Venketesan, R. (2010). Biogenic synthesis of silver nanoparticles and their synergistic effect with antibiotics: A study against Gram-positive and Gram-negative bacteria. *Nanomedicine: Nanotechnology, Biology and Medicine*, 6(1), 103-109. doi:10.1016/j.nano.2009.04.006 12. Gade, A. K., Bonde, P., Ingle, A. P., Marcato, P. D., Duran, N., & Rai, M. K. (2010). Exploitation of Aspergillus niger for synthesis of silver nanoparticles. *Journal of Biobased Materials and Bioenergy*, 4(2), 123-129. doi:10.1166/jbmb.2010.1041
13. Ghosh, S., Patil, S., Ahire, M., Kitture, R., Kale, S., Pardesi, K., ... & Bellare, J. (2012). Gnidia glauca flower extract mediated synthesis of gold nanoparticles and evaluation of its chemocatalytic potential. *Journal of Nanobiotechnology*, 10(1), 17. doi:10.1186/14773155-10-17
14. Gopinath, V., MubarakAli, D., Priyadarshini, S., Priyadharsshini, N. M., Thajuddin, N., & Velusamy, P. (2013). Biosynthesis of silver nanoparticles from Tribulus terrestris and its antimicrobial activity: A novel biological approach. *Colloids and Surfaces B: Biointerfaces*, 96, 69-74. doi:10.1016/j.colsurfb.2012.12.027
15. Gurunathan, S., Han, J. W., Dayem, A. A., Eppakayala, V., & Kim, J. H. (2014). Green synthesis of silver nanoparticles using Ganoderma neo-japonicum Imazeki: A potential cytotoxic agent against breast cancer cells. *International Journal of Nanomedicine*, 9, 5233-5247. doi:10.2147/IJN.S69714
16. Gurunathan, S., Han, J. W., Eppakayala, V., & Kim, J. H. (2014). Cytotoxicity of biologically synthesized silver nanoparticles in MDA-MB-231 human breast cancer cells. *Biomed Research International*, 2014, 1-10. doi:10.1155/2014/472303
17. Gurunathan, S., Han, J. W., Kwon, D. N., & Kim, J. H. (2014). Enhanced antibacterial and anti-biofilm activities of silver nanoparticles against Gram-negative and Grampositive bacteria. *Nanoscale Research Letters*, 9(1), 373. doi:10.1186/1556-276X-9-373
18. Gurunathan, S., Kalishwaralal, K., Vaidyanathan, R., Venkataraman, D., Pandian, S. R. K., Muniyandi, J., ... & Gurunathan, S. (2012). Biosynthesis, purification and characterization of silver nanoparticles using Escherichia coli. *Colloids and Surfaces B: Biointerfaces*, 74(1), 328-335. doi:10.1016/j.colsurfb.2009.07.048
19. Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. *Green Chemistry*, 13(10), 2638-2650. doi:10.1039/C1GC15386B
20. Kaviya, S., Santhanalakshmi, J., Viswanathan, B., Muthumary, J., & Srinivasan, K. (2011). Biosynthesis of silver nanoparticles using Citrus sinensis peel extract and its antibacterial activity. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 79(3), 594-598. doi:10.1016/j.saa.2011.03.040

21. Kelly, K. L., Coronado, E., Zhao, L. L., & Schatz, G. C. (2003). The optical properties of metal nanoparticles: The influence of size, shape, and dielectric environment. *Journal of Physical Chemistry B*, 107(3), 668-677. doi:10.1021/jp026731y
22. Khalil, M. M. H., Ismail, E. H., El-Baghdady, K. Z., & Mohamed, D. (2014). Green synthesis of silver nanoparticles using olive leaf extract and its antibacterial activity. *Arabian Journal of Chemistry*, 7(6), 1131-1139. doi:10.1016/j.arabjc.2013.04.007
23. Kim, J. S., Kuk, E., Yu, K. N., Kim, J. H., Park, S. J., Lee, H. J., ... & Cho, M. H. (2007). Antimicrobial effects of silver nanoparticles. *Nanomedicine: Nanotechnology, Biology and Medicine*, 3(1), 95-101. doi:10.1016/j.nano.2006.12.001
24. Lara, H. H., Garza-Treviño, E. N., Ixtepan-Turrent, L., & Singh, D. K. (2010). Silver nanoparticles are broad-spectrum bactericidal and virucidal compounds. *Journal of Nanobiotechnology*, 8(1), 1-8. doi:10.1186/1477-3155-8-1
25. Li, W. R., Xie, X. B., Shi, Q. S., Duan, S. S., Ouyang, Y. S., & Chen, Y. B. (2011). Antibacterial effect of silver nanoparticles on Staphylococcus aureus. *Biometals*, 24(1), 135-141. doi:10.1007/s10534-010-9381-6
26. Mittal, A. K., Bhaumik, J., Kumar, S., & Banerjee, U. C. (2012). Biosynthesis of silver nanoparticles: Elucidation of prospective mechanism and therapeutic potential. *Journal of Colloid and Interface Science*, 370(1), 84-92. doi:10.1016/j.jcis.2011.12.057
27. Mittal, A. K., Chisti, Y., & Banerjee, U. C. (2013). Synthesis of metallic nanoparticles using plant extracts. *Biotechnology Advances*, 31(2), 346-356. doi:10.1016/j.biotechadv.2013.01.003
28. Morones, J. R., Elechiguerra, J. L., Camacho, A., Holt, K., Kouri, J. B., Ramírez, J. T., & Yacaman, M. J. (2005). The bactericidal effect of silver nanoparticles. *Nanotechnology*, 16(10), 2346-2353. doi:10.1088/0957-4484/16/10/059
29. Niraimathi, K. L., Sudha, V., Lavanya, R., & Brindha, P. (2013). Biosynthesis of silver nanoparticles using Alternanthera sessilis (Linn.) extract and their antimicrobial activity. *Asian Pacific Journal of Tropical Biomedicine*, 3(3), 176-180. doi:10.1016/S22211691(13)60043-0
30. Panigrahi, S., Kundu, S., Ghosh, S. K., Nath, S., & Pal, T. (2004). General method of synthesis for metal nanoparticles. *Journal of Nanoparticle Research*, 6(4), 411-414. doi:10.1007/s11051-004-0565-5
31. Philip, D., & Unni, C. (2011). Extracellular biosynthesis of gold and silver nanoparticles using Krishna tulsi (Ocimum sanctum) leaf. *Physica E: Low-dimensional Systems and Nanostructures*, 43(7), 1318-1322. doi:10.1016/j.physe.2011.04.001
32. Prabhu, S., & Poulose, E. K. (2012). Silver nanoparticles: Mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. *International Nano Letters*, 2(1), 32. doi:10.1186/2228-5326-2-32
33. Prior, R. L., Wu, X., & Schaich, K. (2005). Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. *Journal of Agricultural and Food Chemistry*, 53(10), 4290-4302. doi:10.1021/jf0502698

34. Priyadarsini, K. I. (2014). The chemistry of curcumin: From extraction to therapeutic agent. *Molecules*, 19(12), 20091-20112. doi:10.3390/molecules191220091
35. Rai, M., Yadav, A., & Gade, A. (2012). Silver nanoparticles as a new generation of antimicrobials. *Biotechnology Advances*, 27(1), 76-83. doi:10.1016/j.biotechadv.2010.06.004
36. Raza, M. A., Kanwal, Z., Rauf, S., Sabri, A. N., Riaz, S., & Naseem, S. (2016). Size- and shape-dependent antibacterial studies of silver nanoparticles synthesized by wet chemical routes. *Nanomaterials*, 6(4), 74. doi:10.3390/nano6040074
37. Santhosh, S., Alex, S., Mathew, A., Philip, D., & Jacob, C. (2013). Green synthesis of silver nanoparticles and the study of optical properties. *Journal of Molecular Liquids*, 177, 315-322. doi:10.1016/j.molliq.2012.10.006
38. Shankar, S. S., Rai, A., Ahmad, A., & Sastry, M. (2014). Rapid synthesis of Au, Ag, and bimetallic Au core-Ag shell nanoparticles using Neem (Azadirachta indica) leaf broth. *Journal of Colloid and Interface Science*, 275(2), 496-502. doi:10.1016/j.jcis.2004.03.003
39. Sharma, V. K., Yngard, R. A., & Lin, Y. (2009). Silver nanoparticles: Green synthesis and their antimicrobial activities. *Advances in Colloid and Interface Science*, 145(1-2), 83-96. doi:10.1016/j.cis.2008.09.002
40. Singh, P., Kim, Y. J., Singh, H., Wang, C., & Mathiyalagan, R. (2016). Green synthesis of silver nanoparticles using plants: A review. *Biotechnology Advances*, 34(8), 10181027. doi:10.1016/j.biotechadv.2016.10.006
41. Singhal, G., Bhavesh, R., Kasariya, K., Sharma, A. R., & Singh, R. P. (2011). Biosynthesis of silver nanoparticles using Ocimum sanctum (Tulsi) leaf extract and screening its antimicrobial activity. *Journal of Nanoparticle Research*, 13(7), 2981-2988. doi:10.1007/s11051-010-0193-y