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Silver Nanoparticles from Nature: Green Synthesis Methods and Applications - A Review

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Silver nanoparticles (AgNPs) are highlighted by researchers for their special properties. This review explores the green synthesis processes of Nano silver using natural sources and examines their practical applications. Green synthesis uses plant extracts and microorganisms such as bacteria, fungi, and algae. These methods are environmentally eco-friendly and economical and avoid harmful chemicals. The synthesis is primarily the reduction of silver ions to AgNPs through biologically reactive compounds present in natural sources. The green synthesis approach is more sustainable compared to chemical methods, which reduces costs and enhances environmental sustainability. Silver nanoparticles have applications in various fields. However, stable silver nanoparticles that can be widely applied are still a challenge for researchers despite the great diversity of different biological sources, whether from plants with their various parts or microorganisms. In this research, 45 biological sources for the production of AgNPs were identified. Therefore, green synthesis methods for Nano silver from natural sources represent a promising research area that requires significant collaborative efforts. Also, continuous advances in manufacturing techniques and scientific research are expanding the applications of silver nanoparticles into new and unexpected areas.

1. Introduction

Silver nanoparticles play a major role in industrial applications, so it was necessary to synthesize silver nanomaterials from natural sources [1-3]. The size of nanoparticles ranges from 1 to 100 nanometers and comes in various forms, such as organic compounds, metals, and metal oxides. They have many applications due to their unique properties [4, 5]. Traditional methods of producing nanoparticles are toxic, expensive and environmentally unfriendly [6, 7]. Environmentally friendly chemical reagents are used in the synthesis of molecules to reduce the formation of hazardous compounds and thus improve environmental performance [8, 9]. The use of green sources like plants, fungi, algae, bacteria, agricultural waste, or other natural resources has captured the interest of researchers in synthesize nanoparticles sustainably [10]. The stability, dimensions and morphology of AgNPs were confirmed and analyzed using UV-Vis spectroscopy, X-ray diffraction, scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier transform infrared (FTIR) and EDX electron microscopy techniques [11-13].

Synthesis of Nano silver is classified into top-down Strategy and bottom-up Strategy. In the former Strategy, bulk materials are broken down into nanostructures, while in the latter Strategy, atoms or molecules are built to form larger structures. These methods are divided into physical method, chemical method, and biological synthesis. Although physical method and chemical method are often labor-intensive, labor-intensive, and hazardous, biological synthesis offers advantages such as higher yield, solubility, and stability. The selection of energy source, starting materials, and the concentration and ratio of these materials are critical factors to attain the preferred shape and size of silver nanoparticles [7, 14]. Natural synthesis using fungi provides efficient production of nanoparticles. It produces a variety of metabolites. Because natural antimicrobial properties of fungi, metallic nanoparticles enhance the antimicrobial effect [15]. The properties of silver nanoparticles are measured by their shape, size and crystal structure. Several methods are their synthesis like biological, chemical and optical methods. Chemical methods are the easiest, where capping and reducing agents are used to adjust the scale and distribution of the particles. Some of these methods have challenges such as the need for high temperatures and difficulty in separating the particles. The best environmental alternative is utilizing water as a solvent along with safe reducing agents in green manufacturing methods [7].

The eco-friendly approach offers the best balance of cost-effectiveness and environmental responsibility. However, it faces challenges in producing nanoparticles or nanowires in large quantities [16]. Naturally manufactured AgNPs have many applications in various Sectors because of their safety and eco-friendliness [17]. AgNPs have strong antimicrobial activity, excellent catalytic efficiency, and outstanding optical properties.

These properties have placed silver nanoparticles at the forefront of various scientific and industrial applications, ranging from medicine and environmental remediation to electronics and catalysis. However, the synthesis of AgNPs remains a subject of considerable debate within the scientific community, especially regarding the methods used to produce them.

The United Nations' Sustainable Development Goals (SDGs) include 17 goals to tackle global challenges and create a sustainable future [18, 19]. These goals address issues like poverty, hunger, education, clean energy, and climate action. Among them, Goal 3 (Good Health and Well-being), Goal 6 (Clean Water and Sanitation) and Goal 12 (Responsible Consumption and Production) link closely to green nanotechnology. Green synthesis of nanoparticles uses natural resources like plants, microorganisms, and agricultural waste. This method avoids harmful chemicals and lowers environmental impact. It supports sustainability by reducing pollution and energy consumption. These nanoparticles have applications in medicine, agriculture, and environmental protection. Their use highlights how nanotechnology contributes to achieving the SDGs. This review discusses different perspectives on the synthesis of AgNPs, focusing on natural synthesis methods, their benefits and drawbacks, and the ongoing debate among researchers regarding the most effective and sustainable approaches.

2. Historical Background and Conventional Synthesis Methods

The entire journey of silver Nanoparticles begins in ancient times when Silver is used for medicinal purposes and preservation. It was not until the 20th century with new developments in nanotechnology that silver nanoparticles were deliberately synthesized and extensively investigated. Until now, the traditional protocols used for AgNPs synthesis depended on chemical and physical conditions [20].

2.1. Chemical Reduction

Reduction by chemical method is the most common conventional way of manufacturing AgNPs. Usually the partial reduction of a silver salt (e.g., AgNO3) by other reducing agents like sodium borohydride, hydrazine or citrate[21]. The method is also efficient to produce of size and shape controlled AgNPs by changing parameters like reactant concentration, temperature and pH [22].

***Proponents and Criticism of Chemical Reduction**:*

Supporters of chemical reduction claim that it affords a great deal of control over nanoparticle properties, which is critical for applications where nanoscale size and shape may be required (such as in plasmonics devices or drug delivery). Such method can be easily repeated and scaled, which allows it to classify dirty samples at an industrial scale for consistent quality control. It was flagged for its eco-unfriendly nature and health concerns about chemical reduction. The use of toxic chemicals and production of harmful byproducts are serious detrimental risks, particularly when the technology is being scaled up for industrial purposes. These processes are already pretty bad environmentally, and the high energy use associated with them adds to that environmental footprint making them an even less significant option for sustainability in general [23, 24].

2.2. Photochemical and Electrochemical Methods

Photochemical and electrochemical synthesis are some other conventional methods. For instance, photochemical synthesis reduces silver ions to metal under irradiation with the help of a light source and electrochemical methods induce reduction at conductive substrate by applying an electrical potential. These methods provide an additional dimension not only for particle size but also shape control of the nanocrystals [25-27].

Advantages and Challenges of Photochemical and Electrochemical Methods

Such methods are in high demand due to their ability to achieve precise control over the optical properties of nanoparticles that is critical for many applications involving sensors, contrast agents or other imaging materials. Additionally, they work in mild conditions, meaning less high temperatures or a pressure is necessary. Specialized equipment is required as well and the possibility of generating toxic by-products creates a bit too high potential downside. These techniques are usually not very scalable, which can hinder their application to more industrial uses.

3. Green Synthesis Methods: A Sustainable Alternative

Due to the health and environmental considerations of conventional synthetic techniques, green synthesis has risen as an environmentally benign option. Silver nanoparticles can be produced without toxic chemicals using silver extracted plant extracts, microorganisms or algae by green synthesis methods. The technique performed under each of these conditions complies with green chemistry principles by minimizing the amounts and hazards abated, while also utilizing renewable resources.

3.1. Plant-Based Synthesis

One of the most extensively studied green synthesis methodologies is that from plant-based. These plant extracts contain various bioactive compounds namely flavonoids, terpenoids as well as polyphenols which helps in the reduction of silver ions and simultaneous stabilization of resultant nanoparticles. Among all the part of plant for green synthesis of silver nanoparticles, leaves appeared to be more favorable as they have some bioactive molecules play an essential role in reducing and stabilization process. As Illustrated in Figure 1. The properties of nanoparticles are influenced by several factors, including the extract size, temperature reaction time and silver concentration as well as the pH. Preparation is by extracting the plant material with water or another solvent, then combining it with a silver salt solution and stirring with slight heating until the color changes, indicating the formation of AgNPs [28-31]. Plant compounds play a role in stabilizing and directing particle shape and size [32-34]. Natural plant components contain primary and secondary compounds that act as reductants for silver ions. These natural plant components result in stable nanoparticles with desired shapes and sizes [35-37]. One of the plant extracts for producing silver nanoparticles using a green and environmentally friendly method is banana peels. The color changes in the reaction showed the conversion of silver ions into nanoparticles [38]. Emblica officinalis produces AgNPs with face-centered cubic structure in an environmentally friendly manner with a size ranging from 15 to 30 nm [39]. Silver nanoparticles are manufactured using green synthesis methods and have environmental benefits compared to conventional chemical methods [3, 36]. Green synthesis, silver nanoparticles vary according to the plant parts such as the root, seed, stem or leaves [17]. Table 1 shows the average size of the silver nanoparticles that were synthesized from the plant. Recent studies have shown that silver nanoparticles prepared from plant extract are biocompatible, non-toxic, antiviral, antibacterial and anticancer[40, 41]. Figure 2 illustrates the diverse morphologies of silver nanoparticles synthesized using different plant extracts, highlighting the variability influenced by the choice of biological source.

Table 1: Average particle size of AgNP which synthesis from plant

Plants	Average Particle Size	
Swertia paniculata extract	31 - 44 nm	[42]
Ocimum tenuiflorum	21 nm	[43]
Solanum trilobatum	35–70 nm	[44]
Medicago sativa L	50–55 nm	[45]
Justicia glauca	32.5 ± 0.25 nm	[46]
Lallemantia royleana leaf	34.47 ± 1.6 nm	[47]
Jatropha leaf extract	8.61 - 24.24 nm	[48]
Aloe Vera Extract	30 – 35 nm	[49]
Orange peels	7.2 nm	[50]
Green tea leaves	14.2 nm	[50]
Clove buds	13.7 nm	[50]
Syzygium cumini	19.04 - 40.11 nm	[51]
Citrus sinensis Peels	9 nm	[52]
Corn Silk peel	53 nm	[53]
Pomegranate peel	9.5 nm	[54]
Banana peel	16.2 nm	[54]
Tangerine peel	68.3 nm	[54]
Lemon peel	25.1 nm	[54]
Hemidesmus indicus	73.2 nm	[55]
Jujube seed extract	17.7 - 14.2 nm	[56]
Abutilon hirtum	15–30 nm	[57]
Potentilla fulgens	10–20 nm	[58]
Emblica officinalis	15–30 nm	[39]
Pistacia atlantica	20–30 nm	[59]
Red seaweed	79 nm	[60]
Calotropis gigantea	92 ± 19 nm	[61]
Indoneesiella echioides	~29 nm	[62]
Pepper plant leaves	23- 73 nm	[63]
Pistachio nut shells	2 - 18 nm	[64]

Supporters of Plant-Based Synthesis

Proponents of this method highlight its environmental benefits, as it avoids the use of harmful chemicals and reduces energy consumption. The use of plant materials, which are often abundant and inexpensive, also makes this method cost-effective. The simplicity of the process, which typically requires only mild conditions, makes it accessible for widespread use, particularly in developing regions with rich biodiversity.

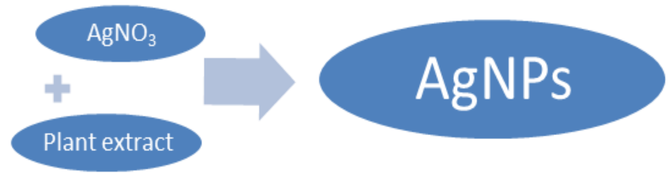

Figure 1: Synthesis of AgNPs from plant extract

Criticism of Plant-Based Synthesis

Plant-based synthesis is not without its challenges. The variability in the composition of plant extracts, which can be influenced by factors such as geographical location, climate, and extraction methods, can lead to inconsistencies in the size, shape, and stability of the nanoparticles. This lack of reproducibility poses a significant barrier to the standardization of the process, which is critical for industrial applications. The scalability of this method remains a concern, as producing large quantities of nanoparticles with consistent quality can be difficult.

3.2. Microbial and Algal Synthesis

Microbial synthesis involves using bacteria, fungi, and algae to produce silver nanoparticles. These microorganisms possess natural reducing agents that can convert silver ions into nanoparticles[65]. AgNPs synthesized using Aspergillus sydowii fungal extracts demonstrated cubic crystalline properties, polydisperse spherical shapes (1-24 nm), and exhibited antifungal and antiproliferative activities, offering an eco-friendly approach for biomedical applications[10]. The ideal conditions for nanoparticle synthesis from fungi include 2 mmol of silver nitrate, a fungal biomass volume three times that of the silver salt, a pH 9 and a temperature of 28°C [66, 67]. Silver nanoparticles are produced from bacteria by using bacterial strains that possess the ability to reduce silver ions to silver nanoparticles. Bacteria are grown in a suitable nutrient medium. The bacterial culture is then collected and the cells are separated from the medium. Cell-free filtrate containing enzymes and natural reducing agents from bacteria is used. Silver nitrate is added to the filtrate and kept under specific temperature and dark conditions, where the bacteria gradually reduce silver ions to silver nanoparticles [68, 69]. Table 2 demonstrates the average size of the AgNPs that were synthesized from Algae, fungi or bacteria. Figure 3 illustrates the diverse morphologies of silver nanoparticles synthesized using different microorganisms, showcasing the influence of microbial species on particle size, shape, and uniformity.

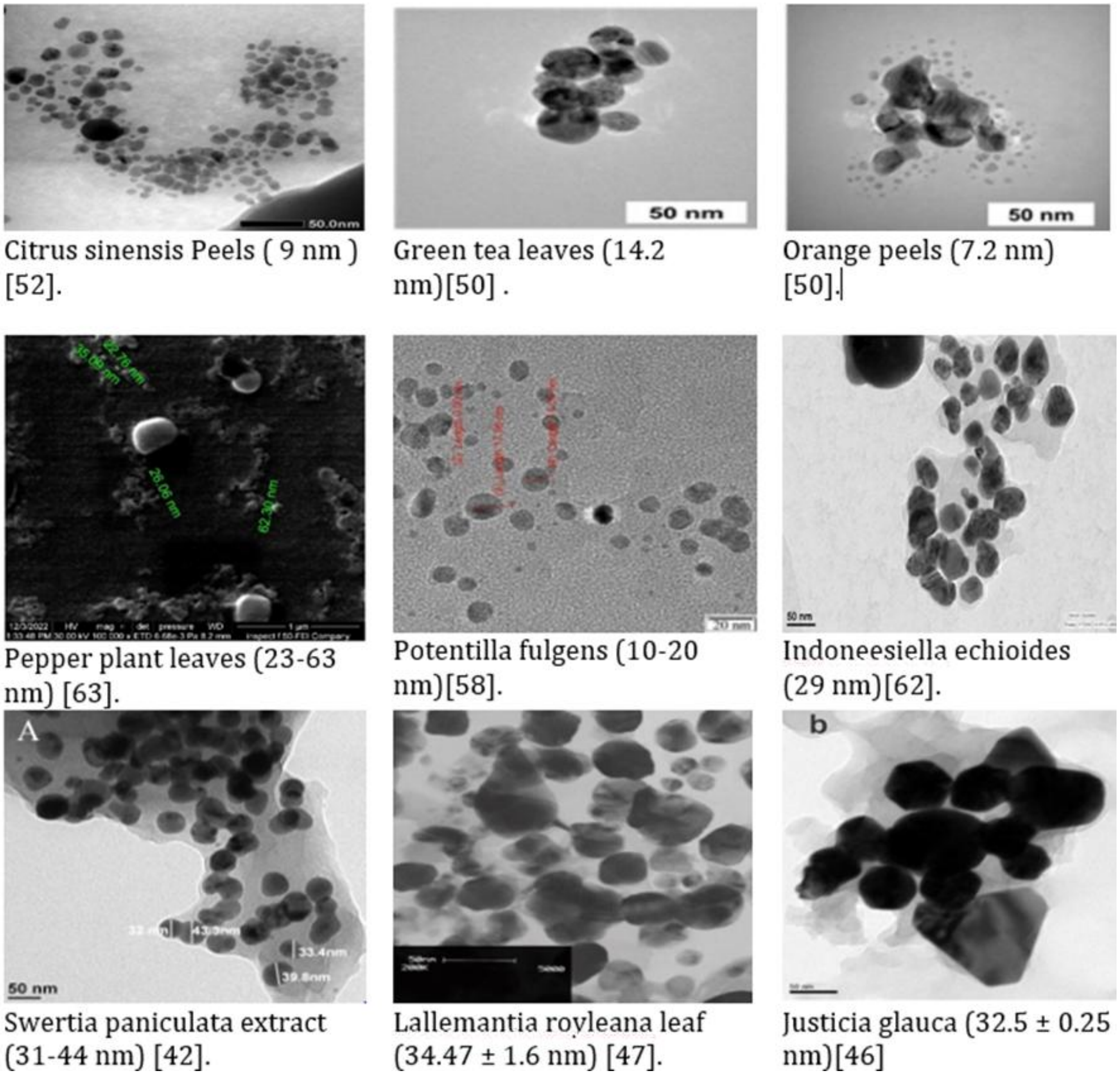

Figure 2: Morphologies of silver nanoparticles synthesized from various plant extracts

Advantages of Microbial and Algal Synthesis

Advocates argue that microbial and algal synthesis methods offer several advantages, including the potential for high yields and the ability to manipulate growth conditions to control nanoparticle characteristics[73, 74]. These methods are also scalable, as microorganisms can be cultured in large quantities, and the process can be adapted for industrial production. The use of biological systems can lead to the formation of nanoparticles with unique properties, such as enhanced biocompatibility, which are particularly valuable in biomedical applications[75, 76]. Figure 4 Overview of biological strategies for the synthesis of silver nanoparticles (AgNPs).

Challenges

Although these alternatives would be environmentally friendlier means of production, they could only improve so much upon the complex biological systems that are basis in algal and microbial synthesis methods. Some can be slow growing microorganisms, requiring longer production times compared to conventional processes. As the mechanisms responsible to trigger these nanoparticles biosynthesis is still not clear, therefore controlling this is too difficult and ultimately conclusion are in more randomized manner. Further research is needed to determine the limitations of these methods and how they can be scaled up whilst still achieving quality [77]. Figure 5 highlights the advantages of green synthesis in comparison to chemical and physical methods.

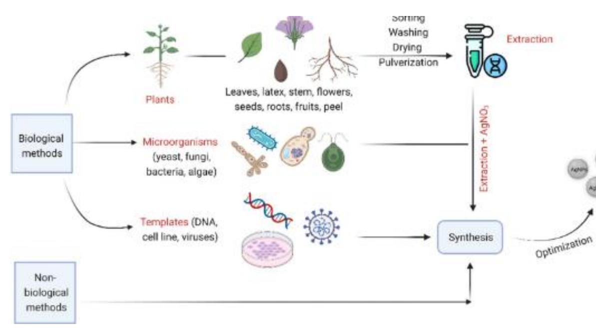

Figure 4: Biological strategies for AgNPs synthesis [20]

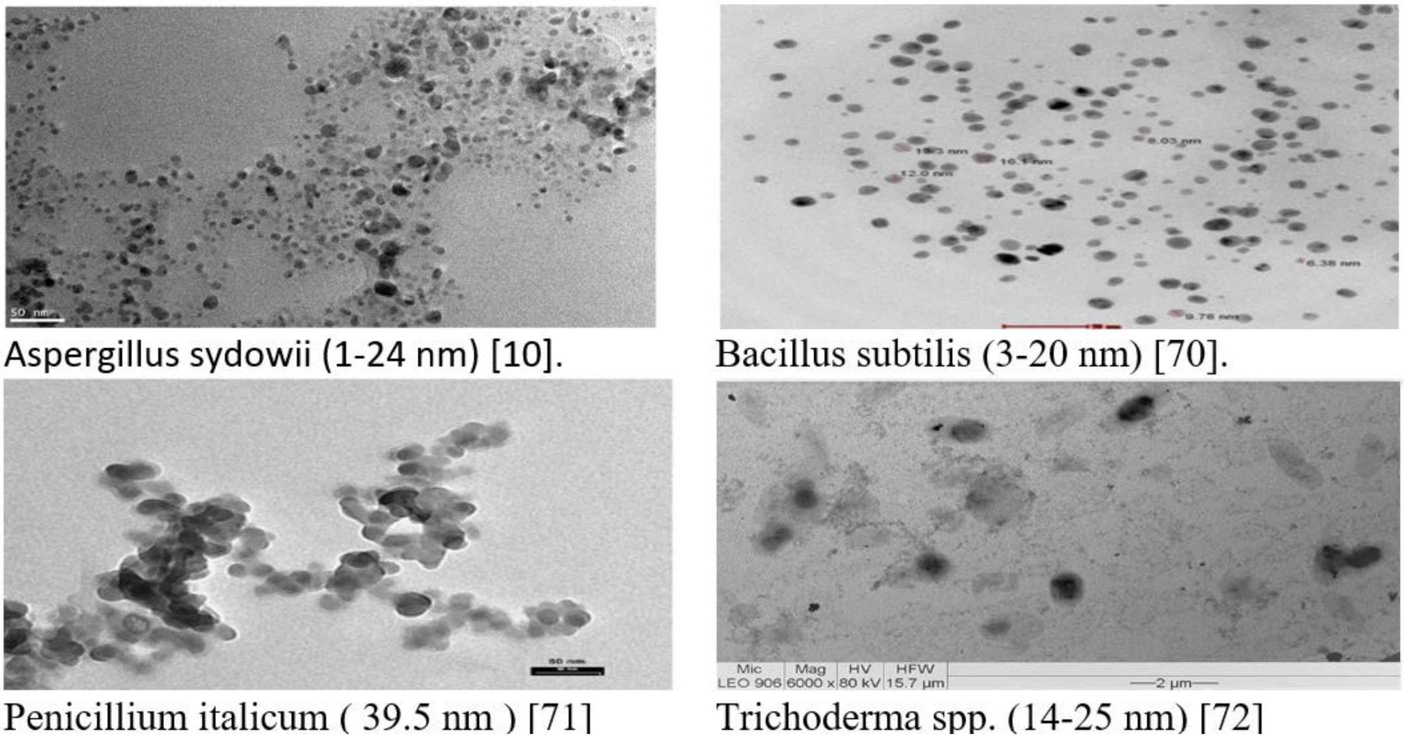

Figure 3: Morphologies of silver nanoparticles synthesized from various microorganism

Table 2: Average Particle Size of AgNPs which synthesis from Algae, fungi or bacteria

Algae, fungi or bacteria	Average Particle Size
Aspergillus sydowii	1 to 24 nm [10]
Fusarium oxysporum	25–100 nm [66]
Cladosporium cladosporioides and Rhizoctonia solani	10.100 nm [78]
Trichoderma harzianum	50.7–58.80 nm [79]
Pseudomonas mandelii	1.9–10 nm [8]
Aspergillus terreus	20 -140 nm [68]
Pilimelia columellifera	12.7 nm [80]
Nostoc sp.	51-100 nm [81]
Desertifilum sp.	4.5 to 26 nm [82]
Bacillus subtilis	3 to 20 nm [70]
Bacillus safensis	22.77 to 45.98 nm [11]
Colletotrichum siamense	79.036 nm [83]
Trichoderma spp.	14 to 25 nm [72]
Aspergillus niger	3–13 nm [84]
Candida albicans	60.88 - 65.57 nm [85]
Penicillium italicum	39.5 nm [71]

4. Applications of Green-Synthesized Silver Nanoparticles

Green-synthesized AgNPs have broad utility in medical applications, environmental decontamination processes and food packaging. These features, in addition to biocompatibility and eco-friendly nature of the green synthesized nanoparticles have brought significant interest for exploiting it wherever safety and environmental attention are a serious requirement[87-91].

4.1. Biomedical Applications

Green-synthesized AgNPs is considered safe, non-toxic and environmentally friendly bio-nanomaterials with a great future perspectives in various biomedical applications such as antimicrobial coatings, wound dressings for treating burn injuries or chronic wounds and drug delivery systems[2, 39, 92]. In addition to having potent antimicrobial activity, they can also be chemically modified and conjugated with targeting molecules such as antibodies or peptides for targeted delivery in medical applications[53]. For instance, AgNPs study was carried out through the green synthesis from root extract of Potentilla fulgens to assess their wound healing activity[53]. The outcomes demonstrated that nanoparticles possessed stable form in the sphere with 10–20 nm size and the wound healing rate was remarkably accelerated by applying topical gel on experimental mice[58, 93]. The best antibacterial activity is observed against E. coli and S. aureus of all nano silver synthesized from Emblica officinalis extract. At 100 μg/ml, the percent reduction in growth was approximately >90% by only a half hour. These findings manifest the promising biocompatible behavior of silver nanoparticles for biomedical utilization [2, 39, 94].

Targeted Drug Delivery

The excellent application that exists for AgNPs in medicine is as drug delivery systems which are targeted. Surface functionalizations of AgNPs with targeting ligands (anti-bodies) allow these nanoparticles to direct toward sites in the body like cancer cells[95, 96]. Selectively delivering drugs to diseased tissue can increase drug efficacy and reduce side effects making this an attractive approach for diseases such as cancer[86]. Figure 6 illustrates the role of silver nanoparticles in biomedical applications. It is showcasing their importance in enhancing medical technologies and improving healthcare outcomes.

Figure 5: Benefits of green synthesis compared to chemical and physical methods [86]

Challenges in Biomedical Applications

Concerns considered with the use of AgNPs in medicine also include those around toxicity and biocompatibility. Although synthesizing nanoparticles through green method is believed to be less toxic way of synthesis, many in depth studies are required both on health effects and use of these NPs for therapeutic purpose [81, 97, 98].

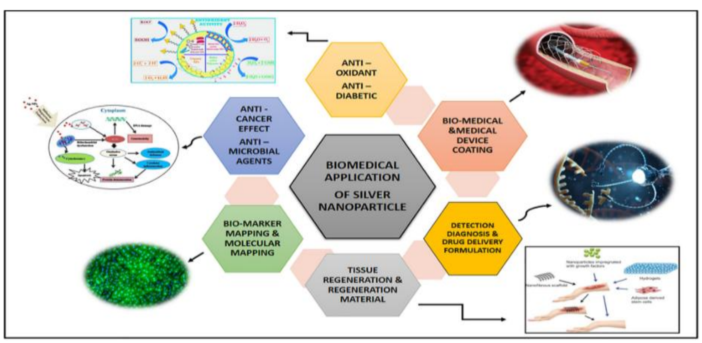

Figure 6: Biomedical application of silver nanoparticle [95]

4.2. Environmental Remediation

Green-synthesized AgNPs also exhibit effective application in environmental remediation. These nanoparticles can degrade dyes, pesticides and heavy metals in water as well as soil [80, 99]. Because they can help initiate chemical reactions and are capable of killing bacteria, viruses etc., enzymes have become important tools in cleaning up contaminated environments.

Sustainability in Environmental Applications

This is of great interest because the use of green-synthesized AgNPs in environmental remediation applications will match with sustainability and environment protection goals. The remediation process is generally more sustainable because the nanoparticles are made with natural resources. Although the release of AgNPs into ecosystems is anticipated, research concerning its consequent impact on ecosystems remains largely inconclusive. In case of Cassava roots the rot intensity has been decreased to (1.75±0.50) by applying AgNPs while control samples reach 5.00, untreated ones [64, 100, 101]

4.3. Industrial Applications

In industry, AgNPs are used in a variety of applications, including catalysis, sensing, and coatings [64, 100, 101]. Green-synthesized nanoparticles are increasingly being explored for these applications due to their environmental benefits and potential for improved biocompatibility[102]. In catalysis, AgNPs are used to accelerate chemical reactions in processes such as the production of fine chemicals and the degradation of pollutants. The ability to produce AgNPs with specific surface properties through green synthesis offers the potential for creating highly efficient and selective catalysts[38]. AgNPs are also used in sensors, where their unique optical properties allow for the detection of chemical and biological substances at very low concentrations. Additionally, they are used in coatings to provide antimicrobial protection for surfaces, such as in medical devices and food packaging.

AgNPs have an even wider array of applications in industry as well including catalysis, sensing and coatings [64, 100, 101]. As a result of these environmental-friendly advantage and potential to improve the biocompatibility, green-synthesized nanoparticles are a subject of growing interest in many applications [102]. Catalysis: AgNPs are also utilized for the catalytic activity to speed up chemical reactions during industrial synthesis of fine chemicals, Ammonia borane (AB) production and degradation processes for toxic waste materials. Green synthesis could generate AgNPs with surface properties adapted accordingly, paving the way for the discovery of new efficient and selective catalysts [38]. Also, the detection of chemical and biological substances at very low concentrations in sensors is possible with AgNPs due to its unique optical properties. They are also desirably used in coatings that impart antimicrobial properties to surfaces, such as medical devices or food packages. Figure 7 various applications of silver nanoparticles across different fields. These nanoparticles are being increasingly utilized in diverse areas such as healthcare, environmental protection, and technology.

Challenges in Industrial Applications

The major obstacles faced in commercializing green-synthesized AgNPs are the industrial scaling up and reproducibility. This represents an impediment to the production of commercial quantities or quality particles and scalable synthesis protocols yet need to be further investigated for the development of green synthesis routes which can also meet industrial demand [78].

4.4. Challenges and Future Perspectives

Despite the benefits of natural synthesis of AgNPs, there are still challenges to overcome for a wider implementation and use.

Reproducibility, scalability, toxicity, environmental impact and regulatory/ethical concerns are among the remaining challenges.

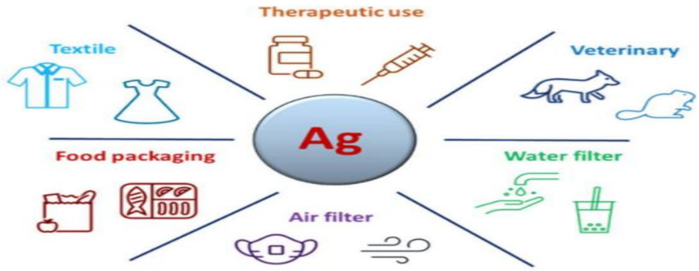

Figure 7: Various applications of silver nanoparticles across different fields [103]

Reproducibility and Standardization

Reproducibility in nanoparticle synthesis is one of the serious problems for green syntheses. Natural resources like plant extracts and microbial cultures are composed differently based on ecological (geographical location, seasonality) conditions as well under extraction processes. These variations can result in the inconsistency of their nanoparticles sizes, shapes and stability which are critical factors for its applications. The green-synthesized AgNPs must capable of ensuring the reproducibility, for achieving consistent results and to meet this commercialization and industrial acceptance. A number of studies have been carried out to develop methods for the standardization of bio-usability, including optimization in extraction practice and research on giving a comprehensive reaction process by tracing certain active compounds that are believed responsible as well as validating prepared formulating protocols which can be universally applicable

Scalability

Also the scalability is a challenge for greener synthesis of AgNPs. Although laboratory-based synthesis has proven green methods feasible, normalising these processes to industry-scale or applications is much harder! And once we scale up, quality is always in demand but so too is the need for cost effectiveness. However, the question is to how extend this green synthesis can be adapted during the production process for making nanoparticles in bulk without any decline in their properties.

Toxicity and Environmental Impact.

Although there was an idea that natural synthesis is more eco-friendly compared to the conventional methods. This is the much practical challenge of AgNPs in terms of toxicity and environmental concerns. The synthesis of nanoparticles can be very harmful to the human health as well as environment if the proper measures are not taken into account. They doodle around the body, making interactions with biological systems that we just don't understand at a fundamental level and probably would lead to toxicity in certain cells. It is also pertinent to note that once in the environment, AgNPs can accumulate and become deleterious for ecosystems by acting on aquatic organisms [1]. These kinds of fears can be eliminated through a detailed toxicological study about the effects of green-synthesized AgNPs on different samples. Nanoparticle exposure is a concern, so strategies for containing and recycling nanoscale materials must be adopted to avoid their release into the environment. This involves investigating what happens to nanoparticles in the environment over extended periods and how they may be offset if found detrimental.

Regulatory and Ethical Considerations

The development and application of AgNPs, particularly those synthesized through green methods, also raise important regulatory and ethical questions. Regulatory frameworks for nanomaterials are still evolving, and there is a need for clear guidelines to ensure the safe production, use, and disposal of AgNPs. This includes establishing standards for the characterization of nanoparticles, as well as for assessing their toxicity and environmental impact. Ethical issues are equally important, particularly given the utilization of natural resources for nanoparticle synthesis. Factors such as the sustainability of plant material supplied and the consequences on biodiversity have to be considered. It is also important to address the socio-economic dimensions of green synthesis, especially in developing countries where these options could offer economic solutions but at the same time be environmentally problematic if not managed properly.

Future Perspectives

Given this reality, the next stage for AgNP synthesis would likely combine both green and conventional methods as needed depending on applications ante portas. More and more, researchers are considering hybrid strategies that combine the environmental benefits of green synthesis with the precision and scalability offered by traditional techniques. One way would be to use conventional techniques to modify or improve the properties of green-synthesized nanoparticles so that a constant and scalable outcome is achieved. We will also need innovative green synthesis methods to solve the current issues. This includes the design of more complex biological systems for nanoparticle synthesis such as engineered microorganisms, or synthetic biology strategies which allows to program NP production. Besides, developments in nanotechnology and materials science may stimulate the identification of fresh pathways for green synthesis which are sustainable as well as economic.

5. Conclusion

Silver nanoparticles (AgNPs) have been increasingly synthesized via different approaches and green methods could represent a new medium for the environmentally friendly production of AgNP. Green synthesis is a biological process which helps in conversion of silver salts into nanoparticles within the plant or microorganism using their compounds. Fungi, bacteria and algae also boost the process via enzymatic activities and narrow spectrum of specific organic compounds, as do plants that contain phenols (e.g., flavonoids) regularly. Green synthesis is beneficial to have practically no environmental impact, competitive cost and that the resultant nanoparticles exhibit biocompatibility rendering them useful for medical applications. We face difficulties on the feasibility, scalability and tailoring nanoparticles in terms of size, shape. However, these constraints and the intricacy of certain processes have reduced its general implementation on a larger scale. Solving these issues will demand continuous research, innovation and cooperation between the scientists and industry. Integrating green approaches for a more complete method may enable the development of scaled-up and eco-friendly-synthesized AgNPs, which can broaden their use in different applications.

Conflict of Interest

The authors declare no conflict of interest.

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