Iraqi Journal of Natural Sciences and Nanotechnology IJNSN

Recent Advances in Plant-Mediated Green Synthesis of Silver Nanoparticles (AgNPs) and Their Biomedical Applications: A Comprehensive Review

Laith S. Alhiti [*1], R. A. Jawad[2], Rafaa A. Abd Alwaahed[3]

[1]Medical physics Department, College of Applied Sciences-Heet, University of Anbar, Iraq

[2]Department of Physics, College of Science, University of Babylon, Hilla, Iraq

[3]Medical physics Department, College of Applied Sciences-Heet, University of Anbar, Iraq

Corresponding Author: laith2011alhiti@uoanbar.edu.iq

Keywords:

Silver nanoparticles (AgNPs); Biomedical; Microorganisms; Green synthesis;

Abstract

The utilization of plant extracts for the green synthesis of silver nanoparticles (AgNPs) has emerged as a prominent method due to its environmentally friendly and cost-effective nature, garnering substantial attention in scientific research. This review article provides an in-depth exploration of the synthesis process, focusing on critical parameters such as temperature, pH level, and reaction duration, which exert significant influence on the size, morphology, and stability of the resultant AgNPs. By leveraging the inherent reducing and stabilizing properties of diverse biomolecules present in plant extracts, researchers can finely adjust the synthesis conditions to yield AgNPs tailored to specific requirements. The biomedical applications of these AgNPs are extensive, encompassing a wide range of functions from serving as antimicrobial agents in wound care and coatings to functioning as versatile drug delivery platforms and diagnostic aids. The pronounced antimicrobial activity of AgNPs renders them particularly valuable in combatting infections and facilitating wound healing processes. Moreover, their biocompatibility and minimal cytotoxicity profile hold promise for diverse therapeutic applications, including but not limited to cancer therapy and tissue engineering. In essence, the green synthesis of AgNPs using plant extracts represents a sustainable and promising avenue with far-reaching implications in the realms of biomedical research and healthcare.

Introduction

With the rapid emergence of new applications, the nanotechnology industry is experiencing significant advancements in the synthesis of nanoparticles with varying shapes and sizes.

Nanotechnology has evolved across various fields, including electronics, optics, environmental science, healthcare, biosensors, biotechnology, and even everyday household products. This evolution has led to a growing demand for safe and efficient nanotechnology solutions. As nanotechnology continues to expand its reach and impact, the need for innovative and reliable approaches becomes increasingly vital [1]. Studies have explored various methods, including physical, chemical, and biological approaches, for synthesizing different metallic nanoparticles. However, drawbacks have been identified with both physical and chemical methods. These drawbacks include the relatively short lifespan of the nanoparticles produced, the high cost associated with these methods, and the production of toxic intermediates during the synthesis process [2]. Researchers have identified several benefits of green synthesis compared to physical and chemical methods. These include simplicity in the synthesis process, rapid production of nanoparticles, absence of toxicity in the synthesized materials, ease of scaling up the synthesis process, and a reduction in the overall cost associated with nanoparticle production [3]. Various studies in the literature have documented the production of diverse metal nanoparticles through biological processes. Among these, silver nanoparticles (AgNPs) synthesized through biological methods have garnered significant attention from researchers. This preference stems from the extensive array of applications these nanoparticles offer, spanning across healthcare, agriculture, water treatment, biosensors, textiles, and the food industry. Achieving controlled synthesis of nanoparticles using different biological systems necessitates careful optimization of several parameters. This process involves several key steps, such as adjusting the pH and temperature of the reaction mixture, optimizing the ratio of biomass to metal ion concentration, determining the appropriate reaction duration, and controlling the agitation rate. Each of these adjustments is crucial for ensuring the efficiency and effectiveness of the reaction. Such optimization efforts are crucial for ensuring the reproducibility and efficiency of the synthesis process [4]. Biological systems exhibit inherent efficiency and distinctive properties conducive to the synthesis of silver nanoparticles (AgNPs). For instance, plants, readily accessible in nature, offer a straightforward and swift method for AgNPs synthesis. This efficiency can be attributed to the presence of various metabolites within plants, including alkaloids, terpenoids, amino acids, vitamins, polysaccharides, proteins, and enzymes. These metabolites play dual roles as both reducing agents, facilitating the conversion of metal ions to nanoparticles, and stabilizing agents, preventing the agglomeration or precipitation of the synthesized nanoparticles [5]. Algae, which can thrive on water surfaces with relative ease, employ cellular reductase enzymes for the synthesis of silver nanoparticles (AgNPs) [6].

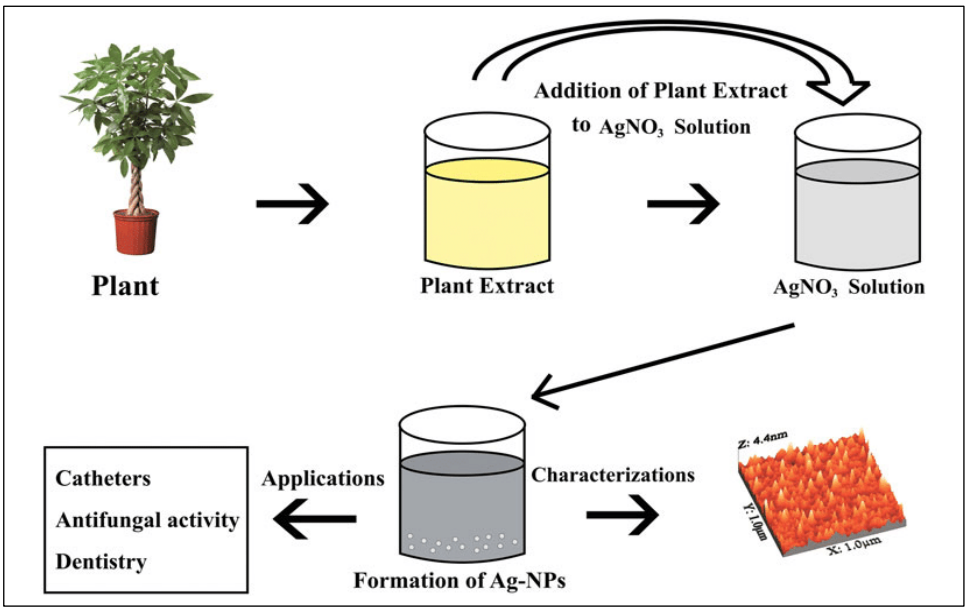

Figure 1 Plant-mediated synthesis of silver nanoparticles.

Researchers have found that maintaining a basic pH level is more conducive for the synthesis of silver nanoparticles (AgNPs), resulting in the production of nanoparticles that are more stable, have a higher yield, exhibit monodispersity, and grow rapidly [7]. Additionally, recent technological advancements have made it possible to monitor synthesis kinetics in real-time using techniques such as synchrotron small-angle scattering, wide-angle synchrotron scattering combined with UV-spectroscopy, and transmission X-ray microscopy (TXM). By fine-tuning nanoparticles using specifically designed processes, it becomes feasible to address existing challenges in various fields including agriculture, medical sciences, textiles, and environmental protection [8].

Several recent studies have concentrated on the antibacterial activity of silver nanoparticles (AgNPs), primarily assessing parameters such as Minimum Inhibitory Concentration (MIC), Zone of Inhibition, and reduction in growth rate [9]. However, a comprehensive understanding of the antimicrobial mechanism of AgNPs has remained elusive. Recent advancements in various biophysical techniques, including proteomics, bioinformatics, Anode Stripping Voltammetry (ASV), and Scanning Transmission Electron Microscopy-High Angle Annular Dark Field (STEM-HAADF), have enabled researchers to explore the underlying mechanisms of AgNPs' action more thoroughly. Yan et al. (2018) utilized proteomic and bioinformatics tools to examine the role of 64 proteins in the interaction between AgNPs and bacteria [10]. Furthermore, STEM-HADDF analysis revealed the distribution of silver released by silver nanoparticles within bacterial cells, leading to damage to the

integrity of the cell membrane and organelles [11]. Furthermore, Anodic Stripping Voltammetry (ASV) was utilized to examine the liberation of silver ions from silver nanoparticles upon interaction with bacterial cells, leading to cellular demise [12]. Moreover, recent advancements have seen the development of innovative methods for delivering AgNPs, such as encapsulation, conjugation, and hybridization with antibiotics, metallic nanoparticles, and polymers [13].

Green synthesis of silver nanoparticles (AgNPs)

While the exact mechanism remains unclear, the process of reducing metal ions using plant extracts was first discovered in the early 1900s. Since then, numerous metals have been successfully reduced using a wide range of plant materials. This method leverages the natural reducing agents found in plants, making it an effective and environmentally friendly approach for metal ion reduction [14]. However, over the past 35 years, there has been considerable interest in the biosynthesis of silver nanoparticles (AgNPs) utilizing extracts from plant tissues, specific plant parts, or even whole plants [15]. The The bioreduction process involves a straightforward method of mixing a metal solution with plant extracts at room temperature. This approach leverages the natural reducing agents present in the plant extracts to facilitate the reduction of metal ions, offering a simple and eco-friendly alternative to more complex chemical methods [14]. During the green synthesis of AgNPs, the main objectives are to improve safety and efficiency while reducing the environmental and societal impact of toxic raw materialsThe properties, yield, quality, and characteristics of the generated AgNPs are predominantly influenced by variables such as the concentrations of plant extract and metal salt, reaction duration, temperature, and pH level. These parameters play crucial roles in controlling the synthesis process and achieving desired outcomes with minimal environmental impact [16].

The selection of plant extract is crucial as various plants and their different parts contain diverse biomolecules that serve as both reducing and stabilizing agents during bioreduction. These biomolecules can significantly impact the surface properties of AgNPs and their tendency to agglomerate in solution, given the multitude of potential interactions with AgNPs [14]. Therefore, the following section briefly explores the various plant types and parts commonly utilized for AgNP biosynthesis.

Green synthesis of AgNPs using extracts derived from leaves, roots, shoots, flowers, and fruits

The green method of manufacturing silver nanoparticles (AgNPs) using extracts derived from leaves, roots, stems, flowers and fruits has several advantages over other conventional methods. It is an environmentally friendly method, uses natural and non-toxic materials, and is characterized by low cost and fast production. This process is done by using plant extracts as sources of reductive and

stabilized materials to manufacture silver nanoparticles. These extracts contain natural chemical compounds such as phenols, flavonoids, amino acids, proteins and enzymes that reduce silver ions and stabilize the nanoparticles formed [17].This process is performed in moderate environmental conditions in terms of temperature, humidity and pH. It is also characterized by speed and efficiency in producing silver nanoparticles with a uniform size distribution and spherical shape. Silver nanoparticles produced in this way have unique physical and chemical properties, such as biological activity, antibacterial properties, and diverse medical and industrial applications [18].

- If the plant extract is sourced from leaves or peels of specific plants, a meticulous procedure ensues. Firstly, a portion of these botanical parts is carefully harvested from suitable locations. Then, they undergo a thorough washing regimen involving two to three rounds of cleansing with tap water to eliminate any adhered dust and soil residues. Subsequently, the botanical parts are subjected to a rinse with distilled water to eradicate any lingering debris. Following this, the clean and freshly washed leaves are left to air-dry in a shaded area for a duration spanning 5 to 7 days. Once adequately dried, they are finely pulverized using a household blender to yield a powdered form. To obtain the plant extract, approximately 0.5 to 10 grams of the dried powder is boiled with an appropriate volume of distilled water [19].

The resulting extracts are then subjected to filtration through filter paper to remove any solid particulates, and each filtrate is collected into individual volumetric flasks (250 ml). These flasks are carefully stored at 4°C to maintain their integrity and purity for future use [20]. It's essential to note that this freshly prepared extract, obtained through meticulous processing, serves as a crucial component in the synthesis of silver nanoparticles (AgNPs). This extract is consistently utilized in its unadulterated state to ensure the optimal performance and efficacy of the synthesized nanoparticles [21].

- When extracting from fresh fruit, a meticulous procedure is followed to ensure purity and efficacy. Firstly, the fruit undergoes a thorough washing process with tap water, followed by a rinse with distilled water to eliminate any surface contaminants. Subsequently, the fruit is carefully sliced and pressed through a fine nylon mesh to extract the juice, ensuring minimal loss of valuable components. The resulting juice extract is then subjected to centrifugation at 10,000 rpm for 10 minutes. This centrifugal force effectively separates any undesirable impurities from the extract, ensuring its clarity and purity.

  Once centrifugation is complete, the clarified extract is carefully transferred into a dark volumetric flask with a capacity of 100 ml. This choice of container helps to shield the extract

from light, which could potentially degrade its constituents. The flask is then sealed and stored at a temperature of 4°C to maintain the stability and integrity of the extract for subsequent experimental procedures [22]. This detailed process ensures that the extract obtained from fresh fruit is of high quality and suitable for use in scientific experiments.

- For extraction from other plant parts, it is crucial to meticulously cleanse the requisite plant material and subsequently combine it with distilled water. Following this, it undergoes a brief boiling process and filtration. The resultant filtrate can be employed promptly or stored at a low temperature for subsequent utilization [23]. The selection of solvent also influences the extraction efficiency, with phenolic and alcoholic extracts demonstrating an augmentation in phytochemical content. Numerous investigations, as outlined in Table 1, have examined the fabrication of AgNPs utilizing diverse plant extracts.

Table 1 Different leaf extracts utilized in the eco-friendly production of AgNPs and their antibacterial efficacy.

No.	Plants	Size (nm)	Shape	Biomedical Applications	Ref.
1.	Tea leaf	20	Spherical	• Escherichia coli • Staphylococcus aureus	[24]
2.	Raphanus sativus	6-38	Spherical	• Aspergillus fumigatus • Fusarium solani	[25]
3.	Clitoria ternatea	20	Spherical	• Bacillus Subtilis • Staphylococcus aureus • Streptococcus pyogenes • Escherichia coli • Pseudomonas aeruginosa • Klebsiella aerogenes	[26]

4.	Prunus yedoensis	18 - 20	Spherical, oval	• Propionibacterium acnes • Staphylococcus epidermidis	[27]
5.	Justicia adhatoda L.	5 - 50	Spherical	• Pseudomonas aeruginosa	[28]
6.	Plantago major	10 - 20	Spherical	• Staphylococcus aureus • Escherichia coli • Pseudomonas aeruginosa	[29]
7.	Artocarpus altilis	20-50	Spherical	• Escherichia coli • Pseudomonas aeruginosa • Staphylococcus aureus • Aspergillus versicolor	[30]
8.	Crotalaria retusa	80	Spherical	• Escherichia coli • Staphylococcus aureus	[31]
9.	Pedalium murex	20-50	Spherical	• Escherichia coli • Klebsiella pneumoniae • Mariniluteicoccus flavus • Pseudomonas aeruginosa • Bacillus subtilis • Bacillus pumilus • Staphylococcus	[32]

				aureus	
10.	Azadirachta indica	34	Spherical	• Staphylococcus aureus • Escherichia coli	[33]
11.	Croton bonplandianum	15-40	Spherical	• Pseudomonas aeruginosa • Escherichia coli • Staphylococcus aureus	[34]
12.	Tamarix gallica	5-40	Spherical	• Escherichia coli	[35]
13.	Lantana trifolia	5 - 70	Spherical	• Staphylococcus aureus • Candida albicans • Escherichia coli • Pseudomonas aeruginosa • Bacillus subtilis	[36]
14.	Taraxacum officinale	5 - 30	Spherical	• Xanthomonas axonopodis • Pseudomonas syringae	[37]
15.	Lantana camara	20-200	Spherical	• Staphylococcus aureus • Escherichia coli • Pseudomonas aeruginosa • Klebsiella pneumoniae	[38]
16.	Jatropha curcas	20-50	Spherical	• Escherichia coli • Pseudomonas	[39]

				aeruginosa • Bacillus cereus • Salmonella enterica • Listeria monocytogenes • Staphylococcus aureus	
17.	Salvinia molesta	10	Spherical	• Staphylococcus aureus • Escherichia coli	[40]
18.	Protium serratum	74.5	Spherical	• Pseudomonas aeruginosa • Escherichia coli • Bacillus subtilis	[41]
19.	Indoneesiella echioides	29	Spherical	• Rhodococcus rhodochrous • Aeromonas hydrophila • Staphylococcus aureus • Pseudomonas aeruginosa • Candida albicans	[42]
20.	Hydrocotyle rotundifolia	7.39	Spherical	• Escherichia coli	[43]
21.	Maclura pomifera	6-16	Spherical	• Staphylococcus aureus • Bacillus cereus • Escherichia coli • Pseudomonas	[44]

				aeruginosa • Aspergillus niger • Candida albicans	
22.	Paederia foetida Linn.	5-25	Spherical	• Bacillus cereus • Staphylococcus aureus • Escherichia coli • Aspergillus niger	[45]
23.	Talinum triangulare	13.86	Spherical	• Escherichia coli • Salmonella typhi • Bacillus subtilis • Staphylococcus aureus • Candida albicans	[46]
24.	Ricinus communis	8.96	Spherical	• Staphylococcus aureus • Pseudomonas aeruginosa	[47]
25.	Erythrina suberosa	15-34	Spherical	• Staphylococcus aureus • Pseudomonas aeruginosa • Candida krusei • Trichophyton mentagrophytes	[48]
26.	Brassica oleracea L.	30-100	Spherical	• Staphylococcus aureus • Escherichia coli • Candida albicans	[49]
27.	Artemisia	27-53	Spherical	• Escherichia coli • Staphylococcus	[50]

	vulgaris			aureus • Pseudomonas aeruginosa • Klebsiella pneumoniae • Haemophilus influenzae	
28.	Petiveria alliacea L.	16.7-33.74	Spherical	• Escherichia coli • Klebsiella pneumoniae • Staphylococcus aureus	[51]
29.	Ficus ingens	81.37	Spherical	• Escherichia coli • Salmonella typhi • Bacillus cereus	[52]
30.	Thymbra spicata	70.2	Spherical	• Bacillus cereus • Staphylococcus aureus • Escherichia coli • Salmonella typhimurium	[53]
31.	Tecoma stans	2-40	Spherical	• Bacillus subtilis • Staphylococcus aureus • Klebsiella pneumoniae	[54]
32.	Selaginella bryopteris	5-10	Spherical	• Staphylococcus aureus • Escherichia coli • Aspergillus niger	[55]

33.	Camellia sinensis	30	Spherical	• Staphylococcus aureus • Klebsiella pneumoniae	[56]
34.	Kleinia grandiflora	20-50	Spherical	• Pseudomonas aeruginosa • Candida albicans	[57]
35.	Juniperus procera	30-90	Spherical and cubic	• Micrococcus luteus • Bacillus subtilis • Proteus mirabilis • Klebsiella pneumoniae • Candida albicans	[58]
36.	Capparis zeylanica	23	Spherical	• Staphylococcus epidermidis • Enterococcus faecalis • Salmonella paratyphi • Shigella dysenteriae • Candida albicans • Aspergillus niger	[59]
37.	Ligustrum lucidum	13	Spherical	• Setosphaeria turcica	[60]
38.	Murraya koenigii	35-80	Spherical	• Escherichia coli • Pseudomonas aeruginosa • Enterococcus faecalis • Candida albicans	[61]
39.	Aspilia pluriseta	1-20	Spherical	• Bacillus subtilis • Staphylococcus aureus	[62]

				• Escherichia coli • Pseudomonas aeruginosa • Candida albicans	
40.	Curcuma longa L.	15-40	Spherical	• Staphylococcus aureus • Pseudomonas aeruginosa • Streptococcus pyogenes • Escherichia coli • Candida albicans	[63]
41.	Cleistanthus collinus	30 - 50	Spherical however not mentioned in manuscript	• Shigella sonnei • Pseudomonas aeruginosa • Staphylococcus aureus • Bacillus subtilis • Shigella dysenteriae • Vibrio cholerae • Proteus mirabilis	[64]
42.	Rice	16.5	Spherical	• Rhizoctonia solani	[65]
43.	Rosmarinus officinalis	29	Sphere	• Staphylococcus aureus • Bacillus subtilis • Escherichia coli • Pseudomonas aeruginosa	[66]
44.	Ceropegia thwaitesii	100	Sphere	• Salmonella typhi • Bacillus subtilis	[67]

				• Staphylococcus aureus • Staphylococcus epidermidis • Vibrio cholerae • Klebsiella pneumoniae • Micrococcus luteus • Proteus mirabilis • Pseudomonas aeruginosa • Shigella flexneri	
45.	Ziziphus jujuba	20-30	Irregular	• Escherichia coli	[68]
46.	Ocimum Sanctum	14.6	Spherical	• Escherichia coli	[69]
47.	Ficus palmata	28 - 33	Spherical	• Streptococcus pneumoniae • Escherichia coli • Pseudomonas aeruginosa • Klebsiella pneumoniae • Proteus vulgaris	[70]
48.	97 Andrographis paniculata	40 and 60	Cubic	• Pseudomonas aeruginosa • Escherichia coli • Vibrio cholerae • Shigella flexneri • Bacillus subtilis	[71]

				• Staphylococcus aureus • Micrococcus luteus	
49.	Andrographis echioides	68.06-91.28	Cubic, pentagonal, hexagonal	• Escherichia coli • Staphylococcus aureus • Salmonella typhimurium • Micrococcus luteus • Pseudomonas aeruginosa	[72]
50.	Pedalium murex	10 - 50	Spherical	• Bacillus subtilis • Staphylococcus aureus • Escherichia coli • Micrococcus flavus • Pseudomonas aeruginosa • Bacillus pumilus • Klebsiella pneumoniae	[73]

Table 2 The utilization of diverse seed, flower, root, Fruit and Gum extracts in the environmentally friendly synthesis of AgNPs and evaluates their antimicrobial properties **.**

No.	**Plants**	**parts**	**Size (nm)**	**Shape**	**Biomedical Applications**	**Ref.**
1.	Grape	seeds	25 - 35	Spherical - polygonal	• Vibrio alginolyticus • Escherichia coli • Vibrio parahaemolyticus	[74]

					• Vibrio anguillarum • Pseudomonas aeruginosa • Alteromonas punctata • Shigella dysenteriae • Staphylococcus aureus	
2.	D. zibethinus	seeds	20 - 75	Spherical - rod shaped	• Escherichia coli • Salmonella typhimurium • Bacillus subtilis • Staphylococcus aureus • Staphylococcus haemolyticus • Salmonella typhi	[75]
3.	Synsepalum dulcificum	seeds	4 - 26	Spherical	• Pseudomonas aeruginosa • Klebsiella granulomatis • Aspergillus flavus • Aspergillus fumigatus • Aspergillus niger	[76]
4.	Linseed	seeds	10 - 35	Spherical	• Streptococcus mutans • Staphylococcus epidermidis • Pseudomonas aeruginosa • Escherichia coli	[77]

					• Staphylococcus aureus • Bacillus subtilis • Actinomyces odontolyticus • Aspergillus niger	
5.	Melissa officinalis	seeds	34.64	Spherical	• E. coli • B. subtilis • B. vallismortis	[78]
6.	Alpinia katsumadai	seeds	12.6	Spherical	• Staphylococcus aureus • Escherichia coli • Pseudomonas aeruginosa	[79]
7.	C. arabica	seeds	20 - 30	Spherical - ellipsoidal	• Escherichia coli • Staphylococcus aureus	[80]
8.	Tectona grandis	seeds	10 - 30	Spherical	• Bacillus cereus • Staphylococcus aureus • Escherichia coli	[81]
9.	Trigonella foenum-graecum	seeds	33.9	Spherical	• Escherichia coli • Klebsiella pneumoniae • Staphylococcus aureus • Salmonella typhi • Pseudomonas aeruginosa • Aspergillus flavus	[82]

					• Candida albicans • Trichophyton rubrum • Penicillium notatum	
10.	Carum copticum	seeds	21.4	Spherical	• Pseudomonas aeruginosa • Serratia marcescens • Chromobacterium violaceum	[83]
11.	N. arbortristis	Flower	5–20	pherical - oval	• Escherichia coli	[84]
12.	Alcea rosea	Flower	7.20	Spherical	• Escherichia coli • Staphylococcus aureus	[85]
13.	Turnera ulmifolia	Flower	32.4	Spherical	• Staphylococcus aureus • Pseudomonas aeruginosa • Escherichia coli • Klebsiella aerogenes	[86]
14.	T. stans	Flower	50–60	Spherical	• Escherichia coli • Staphylococcus aureus	[87]
15.	M. oleifera	Flower	8	Spherical	• Klebsiella pneumoniae • Staphylococcus aureus	[88]
16.	Potentilla fulgens	Root	10–15	Spherical	• Escherichia coli • Bacillus subtilis	[89]
17.	C. barometz	Root	23	Spherical	• Escherichia coli	[90]

					• Staphylococcus aureus • Salmonella enterica • Pseudomonas aeruginosa	
18.	Pelargonium endlicherianum Fenzl.	Root	25–80	Spherical	• Pseudomonas aeruginosa • Escherichia coli • Staphylococcus epidermidis	[91]
19.	Lepidium draba	Root	20–80	Spherical	• Staphylococcus aureus • Bacillus cereus • Salmonella typhimurium • Escherichia coli	[92]
20.	Phoenix dactylifera	Root	15–40	Spherical	• Escherichia coli • Candida albicans	[93]
21.	Psidium guajava	Fruit	2–10	Spherical	• Streptococcus mutans • Bacillus cereus • Escherichia coli • Staphylococcus aureus • Salmonella typhi	[94]
22.	Solanum trilobatum	Fruit	12.50–41.90	Spherical	• S. mutans • E. faecalis • E coli • K. pneumoniae	[95]
23.	Syzygium	Fruit	5–68	Spherical	• Bacillus subtilis • Staphylococcus	[96]

	alternifolium				aureus • Escherichia coli • Klebsiella pneumoniae • Proteus vulgaris • Pseudomonas aeruginosa • Salmonella typhimurium • Alternaria solani • Aspergillus flavus • Aspergillus niger • Penicillium chrysogenum • Trichoderma harzianum	
24.	Citrus lemon	Fruit	2–10	Spherical	• Pseudomonas aeruginosa • Escherichia coli • Staphylococcus aureus	[97]
25.	Momordica charantia	Fruit	78.5–220	Spherical	• Escherichia coli • Salmonella typhi • Staphylococcus aureus • Pseudomonas aeruginosa	[98]
26.	Styrax benzoin	Gum	12–38	Spherical	• Pseudomonas aeruginosa • Staphylococcus aureus	[99]

					• Escherichia coli • Candida tropicalis	
27.	Araucaria heterophylla	Gum	50	Spherical	• Escherichia coli • Streptococcus species	[100]
28.	P. chilensis	Gum	50	Spherical	• Escherichia coli • Streptococcus species	[100]
29.	B. lanzan	Gum	14.7 - 19.8	Spherical	• Escherichia coli • Avibacterium avium • Staphylococcus intermedius • Paenibacillus macerans • Serratia rubidaea • Erwinia mallotivora • Enterococcus faecalis • Staphylococcus haemolyticus • Proteus mirabilis	[101]
30.	M. pudica	Gum	---	Irregular	• Escherichia coli • Schizophyllum commune	[102]

Opimized Conditions for Green Synthesis of AgNps

The efficient green synthesis of silver nanoparticles (AgNPs) and the thorough assessment and comprehension of their antimicrobial effects continue to be intricate procedures, despite extensive research in this domain over the years. Nonetheless, through a review of the existing literature, several hypotheses can be formulated that could contribute to the fabrication of AgNPs with robust antimicrobial attributes. Consequently, given the complexities inherent in the investigation of green synthesis and the antimicrobial potential of AgNPs, the following factors merit consideration during AgNPs synthesis:

1. Selection of plant extract

The solubility of various biochemicals present in plants varies depending on the solvent used for extraction, making the selection of an appropriate extraction solvent crucial for the successful synthesis of silver nanoparticles (AgNPs). Phenolic compounds, for example, exhibit high solubility in solvents such as ethanol, methanol, and their aqueous mixtures (e.g., ethanol-water or methanol-water). Therefore, these solvents are commonly preferred for extraction purposes, along with pure water, which remains the most widely used solvent [103] [104].

2. Temperature

The temperature during the synthesis reaction significantly impacts both the rate of nanoparticle formation and the quality of the resulting product. Controlling the temperature allows researchers to fine-tune the efficiency of the synthesis process and facilitate the creation of precisely defined nanoparticles. Adjusting the temperature parameters enables the manipulation of reaction kinetics, affecting factors such as nucleation and growth rates, which ultimately influence the size, shape, and uniformity of the nanoparticles produced. Therefore, optimizing the temperature conditions is crucial for achieving desired nanoparticle characteristics and ensuring reproducibility in synthesis outcomes.

3. pH level

The pH level of the reaction medium plays a crucial role in dictating the synthesis process of AgNPs. Variations in pH conditions exert a notable influence on the reduction of metal ions and the subsequent stabilization of nanoparticles mediated by biomolecules within the plant extract. Adjusting the pH level enables researchers to meticulously manipulate the characteristics of the synthesized AgNPs, including their size, shape, and stability. By carefully fine-tuning the pH parameters, it becomes possible to optimize the synthesis conditions to yield AgNPs with desired properties tailored for specific applications. This precise control over the pH level ensures reproducibility and consistency in the synthesis process, contributing to the advancement of nanoparticle fabrication techniques [107] [108].

4. Reaction duration

The duration of the interaction between the plant extract and the metal salt solution stands as a critical determinant influencing the kinetics of nanoparticle formation. Extended reaction periods tend to yield larger nanoparticles, whereas shorter durations may produce smaller particles. Through meticulous optimization of the reaction duration, researchers can precisely control the size and morphology of the AgNPs, ensuring they meet the desired specifications.

Fine-tuning the reaction duration allows for the attainment of nanoparticles with tailored properties, facilitating their application in various fields. This optimization process enhances the reproducibility and efficiency of nanoparticle synthesis, fostering advancements in nanotechnology and its diverse applications [109].

Conclusions

Green synthesis of silver nanoparticles is an environmentally friendly method compared to traditional chemical and physical methods. Using plant extracts as reducing and coating agents to prepare silver nanoparticles has many advantages such as low cost, environmental safety, and control of size and shape. The prepared silver nanoparticles have unique properties such as biological activity, antibacterial effect, and optical and electrical properties. Silver nanoparticles prepared by green synthesis method have been used in many biomedical applications such as antibiotics, antioxidants, anticancer, and diagnostic devices. More research is required to understand the interaction mechanisms between silver nanoparticles and living organisms and improve preparation methods to achieve more effective biomedical applications.

References:

1. Abdel-Raouf, N., Alharbi, R. M., Al-Enazi, N. M., Alkhulaifi, M. M., & Ibraheem, I. B. M. (2018). Rapid biosynthesis of silver nanoparticles using the marine red alga Laurencia catarinensis and their characterization. Beni-Suef University Journal of Basic and Applied Sciences, 7(1), 150-157.

2. Abdelghany, T. M., Al-Rajhi, A. M., Al Abboud, M. A., Alawlaqi, M. M., Ganash Magdah, A., Helmy, E. A., & Mabrouk, A. S. (2018). Recent advances in green synthesis of silver nanoparticles and their applications: about future directions. A review. BioNanoScience, 8, 5-16.

3. Acharya, D., Singha, K. M., Pandey, P., Mohanta, B., Rajkumari, J., & Singha, L. P. (2018). Shape dependent physical mutilation and lethal effects of silver nanoparticles on bacteria. Scientific reports, 8(1), 201.

4. Gola, Deepak, Nitin Chauhan, Anushree Malik, and Ziauddin A. Shaikh. "Bioremediation approach for handling multiple metal contamination." In Handbook of metal-microbe interactions and bioremediation, pp. 471-491. CRC Press, 2017.

5. Parthiban, E., Manivannan, N., Ramanibai, R., & Mathivanan, N. (2019). Green synthesis of silver-nanoparticles from Annona reticulata leaves aqueous extract and its mosquito larvicidal and anti-microbial activity on human pathogens. Biotechnology Reports, 21, e00297.

6. Ngeontae, W., Janrungroatsakul, W., Maneewattanapinyo, P., Ekgasit, S., Aeungmaitrepirom, W., & Tuntulani, T. (2009). Novel potentiometric approach in glucose biosensor using silver nanoparticles as redox marker. Sensors and Actuators B: Chemical, 137(1), 320-326.

7. Verma, A., & Mehata, M. S. (2016). Controllable synthesis of silver nanoparticles using Neem leaves and their antimicrobial activity. Journal of radiation Research and applied sciences, 9(1), 109-115.

8. Abdelghany, T. M., Al-Rajhi, A. M., Al Abboud, M. A., Alawlaqi, M. M., Ganash Magdah, A., Helmy, E. A., & Mabrouk, A. S. (2018). Recent advances in green synthesis of silver nanoparticles and their applications: about future directions. A review. BioNanoScience, 8, 5-16.

9. Parikh, R. Y., Ramanathan, R., Coloe, P. J., Bhargava, S. K., Patole, M. S., Shouche, Y. S., & Bansal, V. (2011). Genus-wide physicochemical evidence of extracellular crystalline silver nanoparticles biosynthesis by Morganella spp. PLoS One, 6(6), e21401.

10. Sharma, K., Guleria, S., & Razdan, V. K. (2020). Green synthesis of silver nanoparticles using Ocimum gratissimum leaf extract: characterization, antimicrobial activity and toxicity analysis. Journal of plant biochemistry and biotechnology, 29, 213-224.

11. Chauhan, N., Tyagi, A. K., Kumar, P., & Malik, A. (2016). Antibacterial Potential of Jatropha curcas Synthesized Silver Nanoparticles against Food Borne Pathogens. Front Microbiol. 2016; 7: 1748–1760.

12. Shaikh, S., Nazam, N., Rizvi, S. M. D., Ahmad, K., Baig, M. H., Lee, E. J., & Choi, I. (2019). Mechanistic insights into the antimicrobial actions of metallic nanoparticles and their implications for multidrug resistance. International journal of molecular sciences, 20(10), 2468.

13. Pandey, J. K., Swarnkar, R. K., Soumya, K. K., Dwivedi, P., Singh, M. K., Sundaram, S., & Gopal, R. (2014). Silver nanoparticles synthesized by pulsed laser ablation: as a potent antibacterial agent for human enteropathogenic gram-positive and gram-negative bacterial strains. Applied biochemistry and biotechnology, 174, 1021-1031.

14. Mittal, A. K., Chisti, Y., & Banerjee, U. C. (2013). Synthesis of metallic nanoparticles using plant extracts. Biotechnology advances, 31(2), 346-356.

15. Fatimah, I. (2016). Green synthesis of silver nanoparticles using extract of Parkia speciosa Hassk pods assisted by microwave irradiation. Journal of advanced research, 7(6), 961-969.

16. Dwivedi, A. D., & Gopal, K. (2010). Biosynthesis of silver and gold nanoparticles using Chenopodium album leaf extract. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 369(1-3), 27-33.

17. Beyene, H. D., Werkneh, A. A., Bezabh, H. K., & Ambaye, T. G. (2017). Synthesis paradigm and applications of silver nanoparticles (AgNPs), a review. Sustainable materials and technologies, 13, 18-23.

18. Sivakumar, T. A modern review of silver nanoparticles mediated plant extracts and its potential bioapplications. Int. J. Bot. Stud. 2021, 6(3), 170-175.

19. Ibrahim, H.M. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. Journal of radiation research and applied sciences. 2015, 8(3), 265-275.

20. Vankar, P.S.; Shukla, D. Biosynthesis of silver nanoparticles using lemon leaves extract and its application for antimicrobial finish on fabric. Applied Nanoscience. 2012, 2(2), 163-168.

21. Prathna, T.C.; Chandrasekaran, N.; Raichur, A.M.; Mukherjee, A. Biomimetic synthesis of silver nanoparticles by Citrus limon (lemon) aqueous extract and theoretical prediction of particle size. Colloids and Surfaces B: Biointerfaces. 2011, 82(1), 152-159.

22. Rónavári, A.; Igaz, N.; Adamecz, D.I.; Szerencsés, B.; Molnar, C.; Kónya, Z. ; Pfeiffer, I.;Kiricsi, M. Green silver and gold nanoparticles: Biological synthesis approaches and potentials for biomedical applications. Molecules. 2021, 26(4), 844.

23. Azwanida, N.N. A review on the extraction methods use in medicinal plants, principle, strength and limitation. Med Aromat Plants. 2015, 4(196), 2167-0412.

24. Goswami, S. R., Sahareen, T., Singh, M., & Kumar, S. (2015). Role of biogenic silver nanoparticles in disruption of cell–cell adhesion in Staphylococcus aureus and Escherichia coli biofilm. Journal of Industrial and Engineering Chemistry, 26, 73-80.

25. Ali, S. M., Yousef, N. M., & Nafady, N. A. (2015). Application of biosynthesized silver nanoparticles for the control of land snail Eobania vermiculata and some plant pathogenic fungi. Journal of Nanomaterials, 2015, 1-10.

26. Krithiga, N., Rajalakshmi, A., & Jayachitra, A. (2015). Green synthesis of silver nanoparticles using leaf extracts of Clitoria ternatea and Solanum nigrum and study of its antibacterial effect against common nosocomial pathogens. Journal of Nanoscience, 2015, 1-8.

27. Velmurugan, P., Cho, M., Lim, S. S., Seo, S. K., Myung, H., Bang, K. S., ... & Oh, B. T. (2015). Phytosynthesis of silver nanoparticles by Prunus yedoensis leaf extract and their antimicrobial activity. Materials Letters, 138, 272-275.

28. Bose, D., & Chatterjee, S. (2015). Antibacterial activity of green synthesized silver nanoparticles using Vasaka (Justicia adhatoda L.) leaf extract. Indian journal of microbiology, 55(2), 163-167.

29. Salar, R. K., Sharma, P., & Kumar, N. (2015). Enhanced antibacterial activity of streptomycin against some human pathogens using green synthesized silver nanoparticles. *Resource-efficient technologies*, *1*(2), 106-115.

30. Ravichandran, V., Vasanthi, S., Shalini, S., Shah, S. A. A., & Harish, R. (2016). Green synthesis of silver nanoparticles using Atrocarpus altilis leaf extract and the study of their antimicrobial and antioxidant activity. Materials Letters, 180, 264-267.

31. Ahmed, S., Manzoor, K., & Ikram, S. (2016). Synthesis of silver nanoparticles using leaf extract of Crotolaria retusa as antimicrobial green catalyst. Journal of Bionanoscience, 10(4), 282-287.

32. Anandalakshmi, K., Venugobal, J., & Ramasamy, V. J. A. N. (2016). Characterization of silver nanoparticles by green synthesis method using Pedalium murex leaf extract and their antibacterial activity. Applied nanoscience, 6, 399-408.

33. Ahmed, S., Saifullah, M., Ahmad, B. L., Swami, S., & Ikram, J. (2016). Radiat. Res. Appl. Sci., 9, 1-7.

34. Khanra, K., Panja, S., Choudhuri, I., Chakraborty, A., & Bhattacharyya, N. (2015). Evaluation of antibacterial activity and cytotoxicity of green synthesized silver nanoparticles using Scoparia dulcis. Nano Biomed. Eng, 7(3), 128-133.

35. López-Miranda, J. L., Vázquez, M., Fletes, N., Esparza, R., & Rosas, G. (2016). Biosynthesis of silver nanoparticles using a Tamarix gallica leaf extract and their antibacterial activity. Materials Letters, 176, 285-289.

36. Soman, S., & Ray, J. G. (2016). Silver nanoparticles synthesized using aqueous leaf extract of Ziziphus oenoplia (L.) Mill: Characterization and assessment of antibacterial activity. Journal of Photochemistry and Photobiology B: Biology, 163, 391-402.

37. Ajitha, B., Reddy, Y. A. K., Reddy, P. S., Suneetha, Y., Jeon, H. J., & Ahn, C. W. (2016). Instant biosynthesis of silver nanoparticles using Lawsonia inermis leaf extract: Innate catalytic, antimicrobial and antioxidant activities. Journal of molecular liquids, 219, 474-481.

38. Manjamadha, V. P., & Muthukumar, K. (2016). Ultrasound assisted green synthesis of silver nanoparticles using weed plant. Bioprocess and biosystems engineering, 39, 401-411.

39. Chauhan, N., Tyagi, A. K., Kumar, P., & Malik, A. (2016). Antibacterial potential of Jatropha curcas synthesized silver nanoparticles against food borne pathogens. Frontiers in microbiology, 7, 188541.

40. Verma, D. K., Hasan, S. H., & Banik, R. M. (2016). Photo-catalyzed and phyto-mediated rapid green synthesis of silver nanoparticles using herbal extract of Salvinia molesta and its antimicrobial efficacy. Journal of photochemistry and photobiology B: biology, 155, 51-59.

41. Ajitha, B. Ashok Kumar Reddy Y, Rajesh KM, Sreedhara Reddy P (2016) Sesbania grandiflora leaf extract assisted green synthesis of silver nanoparticles: antimicrobial activity. Mater Today Proc, 3, 1977-1984.

42. Kuppurangan, G., Karuppasamy, B., Nagarajan, K., Krishnasamy Sekar, R., Viswaprakash, N., & Ramasamy, T. (2016). Biogenic synthesis and spectroscopic characterization of silver nanoparticles using leaf extract of Indoneesiella echioides: in vitro assessment on antioxidant, antimicrobial and cytotoxicity potential. Applied Nanoscience, 6, 973-982.

43. Kumari, R., Brahma, G., Rajak, S., Singh, M., & Kumar, S. (2016). Antimicrobial activity of green silver nanoparticles produced using aqueous leaf extract of Hydrocotyle rotundifolia. Oriental Pharmacy and Experimental Medicine, 16, 195-201.

44. Azizian-Shermeh, O. (2017). Einali A. Ghasemi A. Adv. Powder Technol, 28, 3167-3171.

45. Bhuyan, B., Paul, A., Paul, B., Dhar, S. S., & Dutta, P. (2017). Paederia foetida Linn. promoted biogenic gold and silver nanoparticles: synthesis, characterization, photocatalytic and in vitro efficacy against clinically isolated pathogens. Journal of Photochemistry and Photobiology B: Biology, 173, 210-215.

46. Elemike, E. E., Onwudiwe, D. C., Fayemi, O. E., Ekennia, A. C., Ebenso, E. E., & Tiedt, L. R. (2017). Biosynthesis, electrochemical, antimicrobial and antioxidant studies of silver nanoparticles mediated by Talinum triangulare aqueous leaf extract. Journal of Cluster Science, 28, 309-330.

47. Soni, N., & Dhiman, R. C. (2017). Phytochemical, anti-oxidant, larvicidal, and antimicrobial activities of castor (Ricinus communis) synthesized silver nanoparticles. Chinese Herbal Medicines, 9(3), 289-294.

48. Mohanta, Y. K., Panda, S. K., Jayabalan, R., Sharma, N., Bastia, A. K., & Mohanta, T. K. (2017). Antimicrobial, antioxidant and cytotoxic activity of silver nanoparticles synthesized by leaf extract of Erythrina suberosa (Roxb.). Frontiers in molecular biosciences, 4, 14.

49. Ocsoy, I., Demirbas, A., McLamore, E. S., Altinsoy, B., Ildiz, N., & Baldemir, A. (2017). Green synthesis with incorporated hydrothermal approaches for silver nanoparticles formation and enhanced antimicrobial activity against bacterial and fungal pathogens. Journal of Molecular Liquids, 238, 263-269.

50. Rasheed, T., Bilal, M., Iqbal, H. M., & Li, C. (2017). Green biosynthesis of silver nanoparticles using leaves extract of Artemisia vulgaris and their potential biomedical applications. Colloids and Surfaces B: Biointerfaces, 158, 408-415.

51. Lateef, A., Folarin, B. I., Oladejo, S. M., Akinola, P. O., Beukes, L. S., & Gueguim-Kana, E. B. (2018). Characterization, antimicrobial, antioxidant, and anticoagulant activities of silver nanoparticles synthesized from Petiveria alliacea L. leaf extract. Preparative Biochemistry and Biotechnology, 48(7), 646-652.

52. Kavaz, D., Umar, H., & Shehu, S. (2018). Synthesis, characterization, antimicrobial and antimetastatic activity of silver nanoparticles synthesized from Ficus ingens leaf. Artificial cells, nanomedicine, and biotechnology, 46(sup3), S1193-S1203.

53. Erci, F., Cakir-Koc, R., & Isildak, I. (2018). Green synthesis of silver nanoparticles using Thymbra spicata L. var. spicata (zahter) aqueous leaf extract and evaluation of their morphology-dependent antibacterial and cytotoxic activity. Artificial cells, nanomedicine, and biotechnology, 46(sup1), 150-158.

54. Biswas, A., & Rokhum, L. (2018, March). Bio derived synthesis of silver nanoparticles from Tecoma stans leaf extract and its photocatalytic and antimicrobial activity. In Int. Conf. Systems and Processes in Physics, Chemistry and Biology, Silchar, Assam (pp. 1-7).

55. Biswas, A., Chawngthu, L., Vanlalveni, C., Hnamte, R., Lalfakzuala, R., & Rokhum, L. (2018). Biosynthesis of silver nanoparticles using Selaginella bryopteris plant extracts and studies of their antimicrobial and photocatalytic activities. Journal of Bionanoscience, 12(2), 227-232.

56. Onitsuka, S., Hamada, T., & Okamura, H. (2019). Preparation of antimicrobial gold and silver nanoparticles from tea leaf extracts. Colloids and Surfaces B: Biointerfaces, 173, 242-248.

57. Kanagamani, K., Muthukrishnan, P., Shankar, K., Kathiresan, A., Barabadi, H., & Saravanan, M. (2019). Antimicrobial, cytotoxicity and photocatalytic degradation of norfloxacin using Kleinia grandiflora mediated silver nanoparticles. Journal of Cluster Science, 30(6), 1415-1424.

58. Ibrahim, E. H., Kilany, M., Ghramh, H. A., Khan, K. A., & ul Islam, S. (2019). Cellular proliferation/cytotoxicity and antimicrobial potentials of green synthesized silver nanoparticles (AgNPs) using Juniperus procera. Saudi Journal of Biological Sciences, 26(7), 1689-1694.

59. Nilavukkarasi, M., Vijayakumar, S., & Kumar, S. P. (2020). Biological synthesis and characterization of silver nanoparticles with Capparis zeylanica L. leaf extract for potent antimicrobial and anti proliferation efficiency. Materials Science for Energy Technologies, 3, 371-376.

60. Huang, W., Yan, M., Duan, H., Bi, Y., Cheng, X., & Yu, H. (2020). Synergistic antifungal activity of green synthesized silver nanoparticles and epoxiconazole against Setosphaeria turcica. Journal of Nanomaterials, 2020, 1-7.

61. Chahande, R. K., Mehere, B. A., Pantawane, P. K., Chouke, P. B., & Murai, S. R. (2020). Bio-inspired synthesis of silver nanoparticles assisted Murraya koneigii leaf extract and its antimicrobial activity. Materials Today: Proceedings, 29, 923-928.

62. Nyabola, A. O., Kareru, P. G., Madivoli, E. S., Wanakai, S. I., & Maina, E. G. (2020). Formation of silver nanoparticles via Aspilia pluriseta extracts their antimicrobial and catalytic activity. Journal of Inorganic and Organometallic Polymers and Materials, 30, 3493-3501.

63. Maghimaa, M., & Alharbi, S. A. (2020). Green synthesis of silver nanoparticles from Curcuma longa L. and coating on the cotton fabrics for antimicrobial applications and wound healing activity. Journal of Photochemistry and Photobiology B: Biology, 204, 111806.

64. Lourthuraj, A. A., Selvam, M. M., Hussain, M. S., Abdel-Warith, A. W. A., Younis, E. M., & Al-Asgah, N. A. (2020). Dye degradation, antimicrobial and larvicidal activity of silver nanoparticles biosynthesized from Cleistanthus collinus. Saudi journal of biological sciences, 27(7), 1753-1759.

65. Kora, A. J., Mounika, J., & Jagadeeshwar, R. (2020). Rice leaf extract synthesized silver nanoparticles: An in vitro fungicidal evaluation against Rhizoctonia solani, the causative agent of sheath blight disease in rice. Fungal biology, 124(7), 671-681.

66. Ghaedi, M., Yousefinejad, M., Safarpoor, M., Khafri, H. Z., & Purkait, M. K. (2015). Rosmarinus officinalis leaf extract mediated green synthesis of silver nanoparticles and investigation of its antimicrobial properties. Journal of Industrial and Engineering Chemistry, 31, 167-172.

67. Muthukrishnan, S., Bhakya, S., Kumar, T. S., & Rao, M. V. (2015). Biosynthesis, characterization and antibacterial effect of plant-mediated silver nanoparticles using Ceropegia thwaitesii–An endemic species. Industrial crops and products, 63, 119-124.

68. Gavade, N. L., Kadam, A. N., Suwarnkar, M. B., Ghodake, V. P., & Garadkar, K. M. (2015). Biogenic synthesis of multi-applicative silver nanoparticles by using Ziziphus Jujuba leaf extract. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 136, 953-960.

69. Logeswari, P., Silambarasan, S., & Abraham, J. (2015). Synthesis of silver nanoparticles using plants extract and analysis of their antimicrobial property. Journal of Saudi Chemical Society, 19(3), 311-317.

70. Kolya, H., Maiti, P., Pandey, A., & Tripathy, T. (2015). Green synthesis of silver nanoparticles with antimicrobial and azo dye (Congo red) degradation properties using Amaranthus gangeticus Linn leaf extract. Journal of Analytical Science and Technology, 6, 1-7.

71. Vanlalveni, C., Lallianrawna, S., Biswas, A., Selvaraj, M., Changmai, B., & Rokhum, S. L. (2021). Green synthesis of silver nanoparticles using plant extracts and their antimicrobial activities: A review of recent literature. RSC advances, 11(5), 2804-2837.

72. Elangovan, K., Elumalai, D., Anupriya, S., Shenbhagaraman, R., Kaleena, P. K., & Murugesan, K. (2015). Phyto mediated biogenic synthesis of silver nanoparticles using leaf extract of Andrographis echioides and its bio-efficacy on anticancer and antibacterial activities. Journal of Photochemistry and Photobiology B: Biology, 151, 118-124.

73. Ulaeto, S. B., Mathew, G. M., Pancrecious, J. K., Nair, J. B., Rajan, T. P. D., Maiti, K. K., & Pai, B. C. (2019). Biogenic Ag nanoparticles from neem extract: their structural evaluation and antimicrobial effects against Pseudomonas nitroreducens and Aspergillus unguis (NII 08123). ACS Biomaterials Science & Engineering, 6(1), 235-245.

74. Xu, H., Wang, L., Su, H., Gu, L., Han, T., Meng, F., & Liu, C. (2015). Making good use of food wastes: green synthesis of highly stabilized silver nanoparticles from grape seed extract and their antimicrobial activity. Food Biophysics, 10, 12-18.

75. Sumitha, S., Vasanthi, S., Shalini, S., Chinni, S. V., Gopinath, S. C., Anbu, P., ... & Ravichandran, V. (2018). Phyto-mediated photo catalysed green synthesis of silver nanoparticles using Durio zibethinus seed extract: antimicrobial and cytotoxic activity and photocatalytic applications. Molecules, 23(12), 3311.

76. Lateef, A., Akande, M. A., Azeez, M. A., Ojo, S. A., Folarin, B. I., Gueguim-Kana, E. B., & Beukes, L. S. (2016). Phytosynthesis of silver nanoparticles (AgNPs) using miracle fruit plant

(Synsepalum dulcificum) for antimicrobial, catalytic, anticoagulant, and thrombolytic applications. Nanotechnology Reviews, 5(6), 507-520.

77. Haseeb, M. T., Hussain, M. A., Abbas, K., Youssif, B. G., Bashir, S., Yuk, S. H., & Bukhari, S. N. A. (2017). Linseed hydrogel-mediated green synthesis of silver nanoparticles for antimicrobial and wound-dressing applications. International journal of nanomedicine, 2845-2855.

78. Pirtarighat, S., Ghannadnia, M., & Baghshahi, S. (2017). Antimicrobial effects of green synthesized silver nanoparticles using Melissa officinalis grown under in vitro condition. Nanomed J, 4(3), 184-190.

79. He, Y., Wei, F., Ma, Z., Zhang, H., Yang, Q., Yao, B., ... & Zhang, Q. (2017). Green synthesis of silver nanoparticles using seed extract of Alpinia katsumadai, and their antioxidant, cytotoxicity, and antibacterial activities. RSC advances, 7(63), 39842-39851.

80. Dhand, V., Soumya, L., Bharadwaj, S., Chakra, S., Bhatt, D., & Sreedhar, B. (2016). Green synthesis of silver nanoparticles using Coffea arabica seed extract and its antibacterial activity. Materials Science and Engineering: C, 58, 36-43.

81. Rautela, A., & Rani, J. (2019). Green synthesis of silver nanoparticles from Tectona grandis seeds extract: characterization and mechanism of antimicrobial action on different microorganisms. Journal of Analytical Science and Technology, 10(1), 1-10.

82. Varghese, R., Almalki, M. A., Ilavenil, S., Rebecca, J., & Choi, K. C. (2019). Silver nanopaticles synthesized using the seed extract of Trigonella foenum-graecum L. and their antimicrobial mechanism and anticancer properties. Saudi journal of biological sciences, 26(1), 148-154.

83. Qais, F. A., Shafiq, A., Ahmad, I., Husain, F. M., Khan, R. A., & Hassan, I. (2020). Green synthesis of silver nanoparticles using Carum copticum: Assessment of its quorum sensing and biofilm inhibitory potential against gram negative bacterial pathogens. Microbial pathogenesis, 144, 104172.

84. Gogoi, N., Babu, P. J., Mahanta, C., & Bora, U. (2015). Green synthesis and characterization of silver nanoparticles using alcoholic flower extract of Nyctanthes arbortristis and in vitro investigation of their antibacterial and cytotoxic activities. Materials Science and Engineering: C, 46, 463-469.

85. Ebrahiminezhad, A., Barzegar, Y., Ghasemi, Y., & Berenjian, A. (2017). Green synthesis and characterization of silver nanoparticles using Alcea rosea flower extract as a new generation of antimicrobials. Chemical Industry and Chemical Engineering Quarterly, 23(1), 31-37.

86. Chandrasekhar, N., & Vinay, S. P. (2017). Yellow colored blooms of Argemone mexicana and Turnera ulmifolia mediated synthesis of silver nanoparticles and study of their antibacterial and antioxidant activity. Applied Nanoscience, 7, 851-861.

87. Hariram, M., Vivekanandhan, S., Ganesan, V., Muthuramkumar, S., Rodriguez-Uribe, A., Mohanty, A. K., & Misra, M. (2019). Tecoma stans flower extract assisted biogenic synthesis of functional Ag-Talc nanostructures for antimicrobial applications. Bioresource technology reports, 7, 100298.

88. Bindhu, M. R., Umadevi, M., Esmail, G. A., Al-Dhabi, N. A., & Arasu, M. V. (2020). Green synthesis and characterization of silver nanoparticles from Moringa oleifera flower and assessment of antimicrobial and sensing properties. Journal of Photochemistry and Photobiology B: Biology, 205, 111836.

89. Mittal, A. K., Tripathy, D., Choudhary, A., Aili, P. K., Chatterjee, A., Singh, I. P., & Banerjee, U. C. (2015). Bio-synthesis of silver nanoparticles using Potentilla fulgens Wall. ex Hook. and its therapeutic evaluation as anticancer and antimicrobial agent. Materials Science and Engineering: C, 53, 120-127.

90. Wang, D., Markus, J., Wang, C., Kim, Y. J., Mathiyalagan, R., Aceituno, V. C., ... & Yang, D. C. (2017). Green synthesis of gold and silver nanoparticles using aqueous extract of Cibotium barometz root. Artificial cells, nanomedicine, and biotechnology, 45(8), 1548-1555.

91. Karatoprak, G. Ş., Aydin, G., Altinsoy, B., Altinkaynak, C., Koşar, M., & Ocsoy, I. (2017). The Effect of Pelargonium endlicherianum Fenzl. root extracts on formation of nanoparticles and their antimicrobial activities. Enzyme and microbial technology, 97, 21-26.

92. Benakashani, F., Allafchian, A., & Jalali, S. A. H. (2017). Green synthesis, characterization and antibacterial activity of silver nanoparticles from root extract of Lepidium draba weed. Green chemistry letters and reviews, 10(4), 324-330.

93. Oves, M., Aslam, M., Rauf, M. A., Qayyum, S., Qari, H. A., Khan, M. S., ... & Ismail, I. M. (2018). Antimicrobial and anticancer activities of silver nanoparticles synthesized from the root hair extract of Phoenix dactylifera. Materials Science and Engineering: C, 89, 429-443.

94. S. Lokina, A. Stephen, V. Kaviyarasan, C. Arulvasu and V. Narayanan, Synth. React. Inorg., Met.-Org., Nano-Met. Chem., 2013, 45, 37–41.

95. Ramar, M., Manikandan, B., Marimuthu, P. N., Raman, T., Mahalingam, A., Subramanian, P., ... & Munusamy, A. (2015). Synthesis of silver nanoparticles using Solanum trilobatum fruits extract and its antibacterial, cytotoxic activity against human breast cancer cell line MCF 7. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 140, 223-228.

96. Yugandhar, P., & Savithramma, N. (2016). Biosynthesis, characterization and antimicrobial studies of green synthesized silver nanoparticles from fruit extract of Syzygium alternifolium (Wt.) Walp. an endemic, endangered medicinal tree taxon. Applied Nanoscience, 6, 223-233.

97. Mosae Selvakumar, P. (2015). Antonyraj CA Babu R. Dakhsinamurthy A. Manikandan N. Palanivel A. Synth. React. Inorg., Met.-Org., Nano-Met. Chem, 46, 291-294.

98. Rashid, M. M. O., Akhter, K. N., Chowdhury, J. A., Hossen, F., Hussain, M. S., & Hossain, M. T. (2017). Characterization of phytoconstituents and evaluation of antimicrobial activity of silver-extract nanoparticles synthesized from Momordica charantia fruit extract. BMC complementary and alternative medicine, 17, 1-7.

99. Du, J., Singh, H., & Yi, T. H. (2016). Antibacterial, anti-biofilm and anticancer potentials of green synthesized silver nanoparticles using benzoin gum (Styrax benzoin) extract. Bioprocess and biosystems engineering, 39, 1923-1931.

100. Samrot, A. V., Angalene, J. L. A., Roshini, S. M., Raji, P., Stefi, S. M., Preethi, R., ... & Madankumar, A. (2019). Bioactivity and heavy metal removal using plant gum mediated green synthesized silver nanoparticles. Journal of Cluster Science, 30, 1599-1610.

101. Siddiqui, M. Z., Chowdhury, A. R., Singh, B. R., Maurya, S., & Prasad, N. (2021). Synthesis, characterization and antimicrobial evaluation of piyar gum-induced silver nanoparticles. National Academy Science Letters, 44, 203-208.

102. Mumtaz, A., Munir, H., Zubair, M. T., & Arif, M. H. (2019). Mimosa pudica gum based nanoparticles development, characterization, and evaluation for their mutagenicity, cytotoxicity and antimicrobial activity. Materials Research Express, 6(10), 105308.

103. Ijaz, I., Bukhari, A., Gilani, E., Nazir, A., Zain, H., & Saeed, R. (2022). Green synthesis of silver nanoparticles using different plants parts and biological organisms, characterization and antibacterial activity. Environmental Nanotechnology, Monitoring & Management, 18, 100704.

104. Roy, S., & Das, T. K. (2015). Plant mediated green synthesis of silver nanoparticles-A. Int. J. Plant Biol. Res, 3, 1044-1055.

105. Farooq, U., Ahmad, T., Khan, A., Sarwar, R., Shafiq, J., Raza, Y., ... & Al-Harrasi, A. (2019). Rifampicin conjugated silver nanoparticles: a new arena for development of antibiofilm potential against methicillin resistant Staphylococcus aureus and Klebsiella pneumoniae. International Journal of Nanomedicine, 3983-3993.

106. Sun, Y., & Xia, Y. (2002). Shape-controlled synthesis of gold and silver nanoparticles. science, 298(5601), 2176-2179.

107. Aghajani Kalaki, Z., SafaeiJavan, R., & Faraji, H. (2018). Procedure optimisation for green synthesis of silver nanoparticles by Taguchi method. Micro & Nano Letters, 13(4), 558-561.

108. Chitra, K., & Annadurai, G. (2014). Antibacterial activity of pH-dependent biosynthesized silver nanoparticles against clinical pathogen. BioMed research international, 2014.

109. Vanlalveni, C., Lallianrawna, S., Biswas, A., Selvaraj, M., Changmai, B., & Rokhum, S. L. (2021). Green synthesis of silver nanoparticles using plant extracts and their antimicrobial activities: A review of recent literature. RSC advances, 11(5), 2804-2837.