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Green Synthesis of Silver Nanoparticles from Plant Extracts in Sri Lanka: A Review of Recent Advances and Bioactivities

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***Abstract*—There are numerous potential applications in green nanoparticle productions for biomedical and environmental fields. The synthesis of metal nanoparticles using plant extracts is considered one of the simplest, most convenient, cost-effective, and environmental friendly methods for avoiding the use of harmful chemicals. Silver, in particular, has long been recognized as a non-toxic and benign agent. Consequently, several eco-friendly processes for rapidly synthesizing silver nanoparticles have emerged, utilizing extracts from various plant parts such as the leaf, bark, and roots. In this review, we summarize the latest research on environmental friendly synthesis of silver nanoparticles (AgNPs) using diverse plant extracts available in Sri Lanka. Additionally, we discuss their potential bioactivities based on the literature.**

Keywords—Biosynthesis, silver nanoparticles, green nanotechnology

I. INTRODUCTION

Nanotechnology is a branch of technology that delves into the nano-scale, a realm characterized by its minute dimensions. This field has experienced a rapid surge in popularity over the past decade due to its wide range of applications. The use of silver to control infections was common in ancient civilizations. The use of silver for therapeutic purposes dates back to the Han Dynasty in China around 1500 B.C.E. During the Phoenician, Macedonian, and Persian empires, silver vessels and plates were commonly utilized [1]. The discovery of antibiotics in the early twentieth century halted the development of silver as an antibacterial agent. However, the recent rise in bacterial resistance to most antibiotics has prompted a reexamination of the possibilities of this ancient therapy, including research with patients utilizing colloidal silver and antibiotics [2]. Nanotechnology is a multidisciplinary field that was discovered in 1959 by Richard Feynman. Norio Tanaguchi defined nanotechnology as "being able to manipulate a single nanoscale object" in 1974. The term "nano" denotes one billionth of a unit, and a nanometer represents precisely that, one billionth of a meter. Nanoparticles (NPs), typically around 1-100 nanometers in size, consist of atomic or molecular scale solid particles with unique physical properties, attributable to their diminutive size and structure. Metal and metal oxide nanoparticles have garnered extensive attention in scientific and technological spheres. This heightened interest arises from their exceptional attributes, which include a high surface-to-volume ratio, excellent dispersion in solutions, and low toxicity. The formation of Ag-NPs has generated considerable interest due to their potential applications in catalysis, plasmonics, optoelectronics, biological sensors, antimicrobial activities, DNA sequencing, Surface-Enhanced Raman Scattering (SERS), climate change and contamination control, clean water technology, energy generation, and information storage and biomedical applications [3]. These bioactivities mainly show 1-100 nm range nanoparticles [4]. In biomedical applications, noble metal NPs such as copper, silver, platinum, gold, zinc, magnesium, and titanium have attracted a lot of attention for their diverse theragnostic properties [5].

There are two primary approaches for synthesizing nanoparticles, known as "top-down" and "bottom-up." In the top-down approach, which involves physical methods, the process begins with a bulk material that is broken down into minuscule particles through size reduction. This is achieved using a range of techniques, including pulse laser ablation, evaporation-condensation, ball milling, pulse wire discharge, and more. Conversely, the bottom-up approach involves the creation of nanoparticles through chemical and biological techniques. This method relies on the self-assembly of atoms into new nuclei, which subsequently grow into nanoscale particles [6].

Various chemical and physical methods have been employed in nanoparticle synthesis, but they often raise environmental concerns. In response, the concept of "green synthesis" has emerged, which involves utilizing materials such as plant extracts, plant biomass, animal proteins, agro-waste, pigments, bacteria, fungi, and viruses for nanoparticle production. This environmentally conscious approach seeks to minimize the ecological footprint of nanoparticle manufacturing [7]. Green tactics, for example, eliminate the need for costly chemicals, use a lot less energy, and produce byproducts and goods that are good for the environment [8]. The use of green nanotechnology in the biomedical, food, and agricultural sectors has a significant potential to improve the quality of life [9]. The overall function of the active components in a plant material determines how an herbal medication acts. That has a synergetic effect as a result of all the constituents. Developing base dosage forms for natural medicines using nanotechnology, such as solid lipid nanoparticles (SLNs), polymeric nanoparticles (nanospheres and nanocapsules), pro-liposomes, liposomes, nano emulsions, etc., provides a great number of advantages in phyto formulation research. The improvement of solubility and bioavailability, stability, toxicity, pharmacological efficacy, prolonged delivery, stimulation of tissue macrophage circulation, and resistance to physical and chemical degradation are a few of these [10]. In nature, there are several ways to regulate the size and form of bio-nanoparticles. For instance, NPs with specified geometries are generated under rigorous genetic control. Biopolymers and polysaccharides had been used to make NPs, while water served as an environmentally friendly solvent and capping/reducing agent [11].

Due to its extensive range of applications in microbiology, chemistry, food technology, cell biology, pharmacology, and parasitology, silver nanoparticles (AgNPs) are among metal NPs that are among the most widely studied nanoparticles from the research community [12]. A variety of ways have been used to create silver nanoparticles, including the sol-gel method, hydrothermal method, chemical vapour deposition, thermal decomposition, microwave-assisted combustion method, etc. [13]. Considerable research has recently been conducted on the biogenic synthesis of silver nanoparticles (AgNPs), employing biomaterials such as plant extracts and microorganisms as reducing agents. AgNPs are created when various biomolecules, such as flavonoids, ketones, aldehydes, tannins, carboxylic acids, polyphenols, and the protein of plant extracts, oxidize Ag^+ to Ag^0 [14].

This review compiles data extracted from published research papers spanning the years 2015 to 2022, focusing on the biogenic synthesis of AgNPs in Sri Lanka. The objective of this review is to inspire researchers to explore the potential of natural resources in the country for silver nanoparticle production through the application of nanobiotechnology. In this review, we delve into the biogenic synthesis and the unique attributes of various plants employed in the creation of silver nanoparticles.

II. Biosynthesis of Silver Nanoparticles From Plant Extract

AgNPs are created by a simple, one-step process that does not produce harmful or expensive chemicals, making them safe, inexpensive, and environmentally friendly. In recent years, substantial research has been done on plants' ability to biosynthesize AgNPs of various sizes, shapes, and stabilities [13]. According to the literature, NPs have been biosynthesized in a variety of plant components, including leaves, roots, seeds, fruits, and stems. Figure 1 describes the common method of biosynthesis of AgNPs [15].

Different plant components are gathered from various sources, properly rinsed with ordinary water, and then washed again with distilled water to remove debris and other undesired items. The sections are then either used as it is to create the extract or dried and crushed into powder. To make the extract, the chopped or crushed plant components are placed in deionized water or alcohol and typically heated below 60 °C for a short period of time, as prolonged high-temperature heating may cause the phytochemicals in the biomass extract to decompose. AgNPs were created by adding plant extracts with various pH levels to solutions containing varying amounts of Ag salt as a metal precursor and then heating them at various temperatures [16]. Because the biomaterials in the extract work as both a reducing agent and a stabilizing agent for the synthesis of AgNPs, this method avoids the usage of chemical stabilizers [17]. Visual color alterations or UV-Vis spectroscopy, which clearly shows a sharp peak owing to surface plasmon resonance (SPR) of AgNPs at about 430-450 nm, can be used to track the development of AgNPs [18]. After the AgNPs have been successfully synthesized, the mixture is centrifuged at a high rpm to separate the NPs, followed by suitable cleaning with solvents and drying in a low-temperature oven [19].

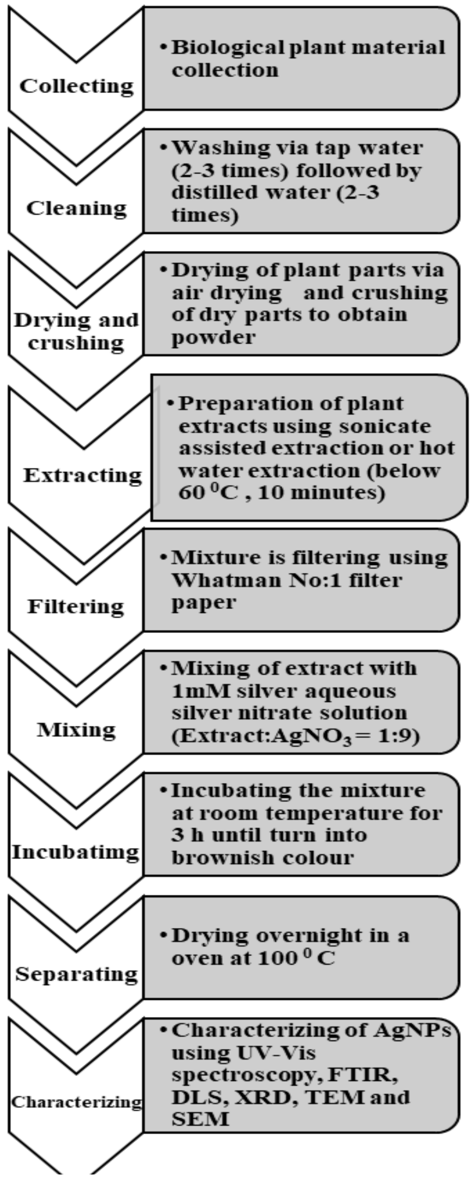

Fig. 1. Biosynthesis of silver nanoparticles using plant extracts

III. Bioactivities and Applications of Silver Nanoparticles

Biogenic production of metal and metal oxide NPs has attracted a lot of attention over the past few decades due to environmental concerns [13]. The purpose of this section is to go over the various Sri Lankan plant component extracts that are used to create AgNPs and their bioactivities. There are few publications available in Sri Lanka for the green synthesis of AgNPs utilizing plant extracts.

Catharanthus roseus flower extracts mediated AgNPs were proved to exhibit excellent antioxidant, antimicrobial, and photocatalytic properties [16],[19]. *Azadiracta indica* (neem) aqueous leaf extract-mediated AgNPs were also found to be highly active against phytopathogenic fungi namely *Mucor* and *Colletritichum* [20]. Another study revealed that antimicrobial activity against *Enterococcus faecalis*, *Staphylococcus aureas*, *Staphylococcus saprophyticus*, and *Salmonella Typi* using *Plectranthus zeylanicus* AgNPs [21]. In this study antibacterial properties were reported against *Staphylococcus aureas* and *Enterococcus faecalis*. *Vigna Unguiculate* (Cowpea) leaf extract-mediated AgNPs were proven to exhibit excellent antioxidant and antimicrobial properties [22]. In another study, *Annona glabra* leaf mediated AgNPs exhibited photocatalytic activity [23] and mosquito larvicidal potential [24]. *Plumbago indica L*. root mediate AgNPs exhibited antimicrobial properties [25]. *Capsicum annuum* mediated AgNPs exhibited excellent antioxidant, antibacterial, and photocatalytic properties [26]. In another work *Chrysanthemum morifolium* Ramat varieties (brown, yellow, purple, pink, and salmon pink) produced AgNPs. Their antioxidant, photocatalytic, and antibacterial activities were reported [27]. Biosynthesized AgNPs suggest that they may be useful in the treatment of disorders caused by free radicals, environmental pollution, and antibiotic resistance. Furthermore, the antibacterial activity of produced AgNPs against *Escherichia coli* and *Staphylococcus aureus* showed. Another interesting work on synthesizing AgNPs using the peels of three citrus fruits (*Citrus tangerina, Citrus sinensis, and Citrus limon*) was reported [28]. In this study reported nanoparticles range in size from 5 to 80 nm and possess a variety of forms such as spherical, triangular, hexagonal, and rod. Furthermore, the antibacterial activity of AgNPs against Gram-negative (*Escherichia coli*) and Gram-positive (*Staphylococcus aureus*) bacteria reported. In another work, *Cinnamon verum* leaf extracts were utilized for the biosynthesis of AgNPs [27]. In this study antioxidant activity was determined by TPC, TFC, TAC, DPPH, and IC50 assays and showed a high antioxidant activity. Furthermore, the photocatalytic and antimicrobial activity reported for AgNPs. In recent times, highly antimicrobial AgNPs were synthesized using aqueous extract of *Eichhornia crassipes* (Mart.) Solms (water hyacinth) which is an invasive plant species found in Sri Lanka [29]. In another recent study, *Chnoospara minima* leaf extract was applied for the production of spherical AgNPs and showed inhibited proliferation of breast cancer cell lines [30]. To date, various plant extract has been utilized for the biosynthesis AgNPs in Sri Lanka (Table 1).

IV. Future Directions

The use of plants for the synthesis of green silver nanoparticles is an interesting and newly discovered area of nanotechnology that has a significant effect on the environment while helping in the long-term sustainability and advancement of nanoscience. Some of the potential uses of these green plant-based NPs include catalysis, cosmetics, medicine, agriculture, food packaging, water treatment, dye degradation, textile engineering, bioengineering sciences, sensors, imaging, biotechnology, electronics, optics, and other biological industries [31]. AgNPs are widely used in nanomedicine, including diagnostics, biomedicines, nanoelectronics, and molecular imaging, because of the enhanced electromagnetic field on their surface. AgNPs are widely used in food packaging to prevent microbiological illnesses because of their antibacterial properties [32]. AgNPs have been used in nanosensors for clinical diagnosis, contaminant analysis, flavor or color analysis, and water analysis [33]. AgNPs have also been used in agriculture. AgNPs can be supplied to crops in addition to pesticides to increase crop productivity. AgNPs are utilized in plant nutrition and disease defense [34]. AgNPs are commonly used as antifungal, antibacterial, anti-inflammatory, and antiviral medicinal agents. AgNPs might be the future impetus for drug delivery to lower drug doses, increase specificity, and reduce toxicity because of their antibacterial properties [35]. These green NPs applications might be further developed in a variety of ways, including phytopathogen treatment in agriculture or water disinfection for environmental cleanup [31]. This environmentally friendly method of producing AgNPs is gaining traction and is anticipated to experience substantial growth in the coming years. In Sri Lanka, several reports have been published on the synthesis of silver nanoparticles using plant extracts, as previously discussed. Nevertheless, there is an unmet need for a commercially viable, cost-effective, and environmentally friendly approach to explore the potential of natural reducing agents in generating silver nanoparticles, which remains largely unexplored. Hence, there is a need for comprehensive research to fully explore the potentials and applications related to the biosynthesis of silver nanoparticles using plant extracts in Sri Lanka. There is a large difference in the chemical contents of plant extracts of the same species gathered from different parts of the world, which may result in different results in different laboratories. This is the major disadvantage of synthesizing silver nanoparticles with plant extracts as reducing and stabilizing agents, and it must be resolved.

The overexploitation of natural resources can result in habitat destruction and the loss of biodiversity. Hence, it is crucial to conduct routine monitoring and characterization of silver nanoparticles produced via green synthesis methods to guarantee their stability and safety. Early detection and resolution of any changes in their properties that might heighten their environmental risk are imperative. While the green synthesis of nanoscale metals holds significant promise, it is constrained by factors such as material selection, synthesis conditions, product quality control, and applications. These factors present challenges to industrial-scale manufacturing and the widespread application of green-synthesized nanoscale metals [36]. The energy consumed during the synthesis process, especially in large-scale production, may still contribute to carbon emissions and environmental impact. To mitigate this, it is essential to employ energy-efficient methods and utilize renewable energy sources to reduce the carbon footprint. Additionally, source materials for green synthesis, such as plant extracts or microbes, should be harvested or cultivated sustainably [36].

Reliable toxicity data is currently lacking, which leaves a knowledge gap regarding the potential harm to human health. While green synthesis methods are generally characterized by the use of less harmful reagents, silver nanoparticles themselves can present ecological risks. Their small size and high surface area can result in heightened reactivity, potentially leading to toxicity in aquatic and terrestrial organisms. As a result, it becomes imperative to undertake thorough toxicity studies to evaluate their impact on diverse ecosystems [37]. Large amounts of silver products released into the environment may disrupt the microbiological ecosystem and potentially lead to bacterial resistance to silver. As a result, other means of sanitization, such as the use of alcohol or bleach for domestic purposes, or the use of 'fixed' silver-containing surfaces that decrease the possibility of environmental discharge, should be considered. The synthesis process could generate wastewater containing unreacted chemicals or byproducts. Ensuring the proper disposal and treatment of this wastewater is crucial to prevent the contamination of natural water bodies. To effectively remove or neutralize any contaminants, advanced treatment methods like filtration, chemical precipitation, or bioremediation may be required [38].

V. Conclusion

The growing interest in green chemistry and nanotechnology in recent decades has spurred the utilization of eco-friendly synthetic approaches for nanomaterial production through plant extracts, microbes, and other sustainable means. Researchers have increasingly focused on the green synthesis of nanoparticles, leveraging environmentally safe methodologies. Plant extract-mediated nanoparticles, due to their cost-effectiveness, harmlessness, availability, and environmental friendliness, have garnered considerable attention among researchers exploring their potential applications in various fields. However, in Sri Lanka, these applications are still in their nascent stages. In this review article, the focus is on the plant-based green synthesis of AgNPs, encompassing aspects such as production, characterization, and potential applications. There is a significant gap in the quest for a commercially viable, cost-effective, and environmentally friendly approach to fully explore the untapped potential of natural reducing agents for silver nanoparticle production in Sri Lanka. This gap highlights the need for comprehensive research to uncover the potentials and applications associated with biosynthesizing silver nanoparticles using plant extracts in Sri Lanka.

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TABLE 1: PLANT EXTRACTS EMPLOYED IN GREEN SYNTHESIS OF SILVER NANOPARTICLES AND THEIR BIOLOGICAL ACTIVITIES REPORTED IN SRI LANKA

Plants		**Plant parts**	**Synthesized AgNP Characterization methods**	**Synthesized AgNP size range and shape**	**Bioactivity / Application**	**Reported Bioactivity**	**References**
Scientific name	***Common name***						
Catharanthus roseus	periwinkle, Madagascar periwinkle, graveyard plant	Flower	UV/Vis spectro-photometric analysis (UV-VIS), Scanning electron microscopy (SEM)	0 – 30 nm, spherical	Antioxidant properties	Total flavonoid content (TFC), total phenolic content (TPC), total antioxidant activity (TAC), ferric-reducing antioxidant properties (FRAP) and DPPH	[17] [39]
					Antimicrobial properties	Antimicrobial activity against Gram-negative *Escherichia coli* using the agar well diffusion method	
					Photocatalytic properties	The removal of methyl orange dye from an aqueous solution under sunlight irradiation in the presence of $NaBH_4$ catalyst (AgNPs concentrations 5000 ppm and 333 ppm)	
Capsicum annuum	Chili, Pepper	Seeds	UV-Vis spectra	25 - 75 nm, spherical	Antioxidant properties	TAC and DPPH assay	[26]
					Antibacterial	Assessed against *Escherichia coli* and *Staphylococcus aureus.*	
					Photocatalytic properties	Assessed using methylene blue (AgNPs concentrations 6350 ppm)	
Chrysanthemum morifolium	Chrysanthemum, Mums	Flowers	UV-VIS, SEM	40 ± 1.2 nm, spherical	Antioxidant activities	TFC, TPC, TAC, DPPH, FRAP	[27]
					Photocatalytic activities	Assessed by the degradation of the model dye methylene blue. (AgNPs concentrations 212 ppm and 3175 ppm)	
					Antibacterial activities	determined on *Staphylococcus aureus* and *Escherichia coli*	
Vigna Unguiculate	cowpeas	Leaves	UV-VIS, SEM	40 nm, spherical	Antioxidant properties	TFC, TPC, TAC, FRAP, ABTS and DPPH assays	[22]
					Antibacterial activities	well diffusion method using gram positive (*Staphylococus aureus*) and gram negative (*Escherichia coli*) bacteria	
Annona glabra	Alligator Apple	Leaves	UV-VIS, SEM	10 - 190 nm, spherical	Photocatalytic Activity	Using Methylene blue solution	[23]
			(UV-VIS), (SEM), dynamic light scattering (DLS) (FTIR)	10 - 100 nm, spherical	Mosquito larvicidal potential	Larvicidal bioassays	[24]
Azadiracta indica	Neem Tree	Leaves	UV-VIS	-	Antimicrobial properties	Be highly active against phytopathogenic fungi namely *Mucor* and *Colletritichum* (greatly suppress concentration of AgNPs 25 mg/1.5)	[20]

Plectranthus zeylanicus	Iruveriya, Variegated Indian Borage	Plant	UV-VIS, SEM	-	Antibacterial activities	Antibacterial potential against *Staphyococcus aureus*, *Enterococcus faecalis* (Minimum concentration range 125-250 µg/mL)	[21]
						Disc diffusion and broth microdilution method against both gram negative and positive bacteria	[40]
Plumbago indica L.	Scarlett Leadwort,Rathnitul	Roots	GC/ MS, Fourier transform infrared spectroscopy (FT-IR) and UV-Vis spectra	-	Antimicrobial activity	Antimicrobial assay	[25]
Citrus tangerina, *Citrus sinensis*, *and Citrus limon*	Citrus	Citrus peel	UV-VIS, (FTIR), and transmission electron microscopy (TEM)	5 - 80 nm triangular, rod, near spherical, spherical, and hexagonal shapes	Antibacterial activity	Antibacterial activity against Gram-negative (*Escherichia coli)* and Gram-positive (*Staphylococcus aureus*) bacteria using a well diffusion method.	[28]
Eichhornia crassipes (Mart.) Solms	Water hyacinth	Plant	UV-VIS, SEM and energy dispersive X-ray	41 - 103 nm, spherical	Antimicrobial activity	Antimicrobial activity tested against *Escherichia coli*, *Staphylococcus aureus* and three different MRSA strains by using broth- micro dilution method.	[29]
Munronia pinnata	Bin kohomba	Stem and leaves	UV-VIS, SEM	39.41 - 82.08 nm spherical	Antimicrobial activity	Antimicrobial activity tested against both gram positive (*Staphylococcus aureus, Bacillus subtilis*) and gram negative bacteria (*Escherichia coli*), using broth dilution (MIC) method (Inhibition concentration range is 0.250 µg/mL- 0.750 µg/mL of Ag NPs concentration)	[30]
Rhipsalis baccifera	Mistletoe cactus	stem					
Stachytarphera indica	Snake weed	Leaves and stem					
Chnoospara minima	Brown algae	Leaves	FTIR, UV-VIS, SEM, DLS, Zeta Potential, and Energy Dispersive X-ray	-	Anti-cancer activity	Inhibit proliferation of breast cancer cell lines	[41]