Original Research Article

J. Funct. Mater. Biomol. 5(2) (2021) pp 483 – 492

SACRED HEART RESEARCH PUBLICATIONS

Journal of Functional Materials and Biomolecules

Journal homepage: www.shcpub.edu.in

ISSN: 2456-9429

A Comprehensive Review on Silver Nanoparticles

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Received on 15 October 2021, accepted on 01 December 2021,
Published online on 15 December 2021

Abstract

Silver nanoparticles have unique features that can contain many applications such as antimicrobial, anti-cancer, larvicidal, catalytic and wound healing. The biogenic synthesis and their pharmacological and other possible applications of silver nanoparticles using plants is gaining traction because of its guaranteed rewards. This important analysis aims to provide an insight into the phytomediated synthesis of silver nanoparticles, their extensive use in different fields and their characterization techniques.

Keywords: Nanoparticles, Nanotechnology, applications, silver nanoparticles.

1 Introduction

Silver is a soft, white and lustrous metal with a high conductivity of electric and thermal. Owing to its medical and therapeutic advantages, it was recognized long before the discovery that microbes are an agent of infections. It is used in many different ways as lotions, ointments, solutions, foils, sutures and colloids. It is the most important therapeutic agent for infectious diseases and surgical infections in medicine.

The advantages of silver outweigh the risks [1]. Nanoscience is a new interdisciplinary topic which relies on the essential characteristics of artifacts of nanosize [2, 3]. Due to its high surface area and its volume ratio, nanoparticles possess wonderful optical, mechanical, magnetic and catalytic properties than bulk material [4, 5]. Silver and gold metal nanoparticles exhibit various colors due to their SPR phenomenon. It is a collective oscillation of the metal nanoparticles free electrons in resonance with the frequency of light wave interactions which causes the SPR band to be visible and infraroth [6].

Various methods are used to manufacture metal nanoparticles, the most common being chemical and physical methods. The above-mentioned processes produce pure and well-defined nanoparticles, but syntheses are chemicals that are harmful, energy-efficient, costly and not biological. Metal nanoparticles' syntheses have been sought after in the past three decades, but plant extract research based nanosynthesis only mushroomed in the last decade [7– 13].

Due to their physical, chemical and biological properties attributable to catalytic activity and bactericidal effects, silver nanoparticles gained attention [14, 14] and find applications in nanobiotechnological investigations. They are used in wound dressings as antimicrobial agents[16–18] and as topical creams for the prevention of wound infections[20].

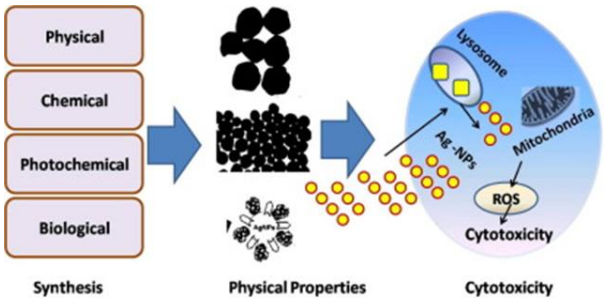

Fig. 1

The green synthesis of silver nanoparticles is based on few review articles. There are documents documenting the escalation of metallic metal nanoparticles such as silver, gold, palladium, antimicrobial, catalytic and electrochemical applications [21]. The synthesis of metal nanoparticles, their special properties as well as the rareness of successful method of synthesis to generate homogeneous dimensions and their applicability were highlighted in Kulkarni and Muddapur (2014)[22]. There are various greener pathways for nanoparticles synthesis of nerovalent metals, metal oxides and salts that highlight recent developments [23].

Synthesis of metallic nanoparticles with plant extracts is cheap, easy to scal and environmentally friendly. In the evaluation of its possible uses, various characterization techniques are used [24].

In a recent article [25, 26] we are addressing the processing of silver nanoparticles, applications in the med-

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ical, health, and environmental issues arising from these nanoparticles and mechanisms of action for human improvement. Antimicrobial characteristics of silver nanoparticles and their futuristic approach in research[27], environmental characteristics of silver nanoparticles in the development of synthetic protocols and applications[28], anti- bacterial characteristics of silver nano-materials, antibacterial mechanisms proposed and potential toxicity of higher organisms[29], existing uses of silver nanoparticles in clinical use.

In measures of oral, ocular and dermal toxicity, the short-term exposure to colloidal AgNPs is not harmful in mice and guinea pigs. For the safe use of colloidal AgNPs, long-term toxicity studies are necessary[30]. A recent paper illustrates the development of greener processes for nanomaterial synthesis, the preparation of functionalized metal particles, progress in core synthesis, surface operation and form regulation and potential challenges for development of greener approaches[2]. Different silver nanoparticles examined for scattering, absorption cross section, extinction, and quadrupolar coupling show that the optical property depends on the size of the Nanoparticles[3].

This study encapsulates the phytomediated synthesis and the various phases of the application of silver nanoparticles. The annual publication analysis showed that research work on the aforementioned subject is steadily increasing and this expected to be more ongoing towards the end of the 21st century.

3. TYPES OF NANOSYNTHESIS

The synthesis of metallic nanoparticles requires the use of chemical, physical and biological means for upward and downward approaches. Silver nanoparticles' biogenic syntheses are listed as below [14]. Several methods of synthesizing silver nanoparticles were employed, including chemical reductions, microwave-assisted syntheses, ultrasound reduction, electrochemical reduction, template process, photo- or photocatalytic reduction, irradiation reduction, the micro-emulsion procedure, as well as the biochemical reduction.

3.1. Chemical Synthesis

A one-pot process was used to reduce AgNO3 with the use of N2H4 alternatively H2O in the presence of CH3COONa at room temperature for 2-3 hours, with water as a solvent[15]. A modified AgClO4 reductor by NaBH4 without the addition of any stabilizing agent obtained the size-controlled output of silver nanoparticles (4–8 nm) [16]. Polyethylene glycol, a particle size mediating silver nanoparticle using β-D-glucose, was found to be based on synthesis time within 24–48 hours [17]. In order to synthesize the stabilized silver nanoparticles, gamma rays were used[38]. AgNPs formed by hydrazine, formalin and ascorbic acid (20 nm) by reducing the [Ag(NH3)2] + sodium-dodecyle micellar solution (SDS) complex [19].

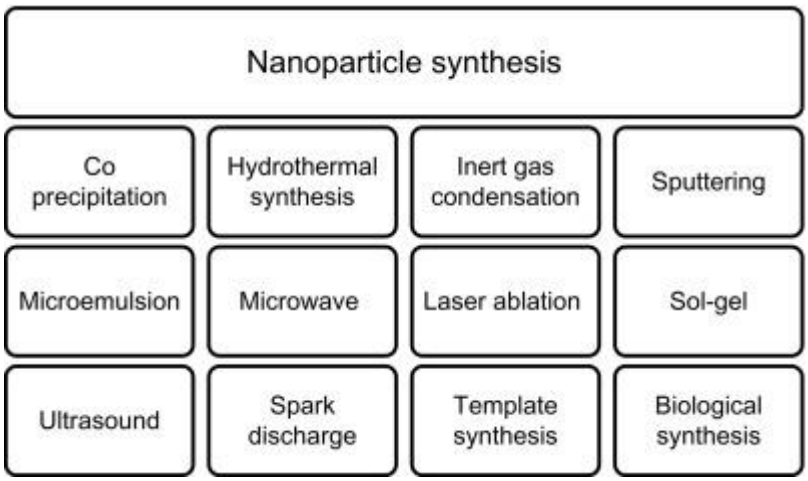

Fig 2.

Silver colloids were generated by the treatment of silver oxalate under micro wave irradiation with polyvinyl pyrrolidone (PVP) and by altering the particle size by several factors[20]. The electrochemical manufacturing of silver nanoparticles by traditional decrease method on a glassy carbon electrode was performed using 1-butyl3-methylimidazolium tetrafluoroborate [11, 12]. AgNPs of 5–10 nm range were obtained with glutathione, an antioxidant, under a microwave irradiation of 30–60 s [23].

The reactions of hydrazine hydrate, sodium citrate as a reductive agent and sodium dodecyl sulphate as a stabilizing agent were obtained in silver nanoparticles (9–30 nm).

The highest antibacterial activity has also been reported at very low levels below 6.74 μg/mL[4]. Microwave irradiation has acquired the reduction of silver ions by carboxymethyl cellulose sodium hydrolyzate (CMS), while traditional methods have not been used. CMS has no effect on the size distribution, whereas the effect of AgNO3 is obvious[45]. Anisotropic silver nanoparticles are quickly obtained by microwave-assisted decomposition in a glycol

medium of silver oxalate using capping agent polyvinyl pyrrolidone (PVP) [6].

Aqueous-gas reaction of silver nitrate solution and ammonia gas leads to the rapid production of AgNPs of 10 nm [7]. Colloidal AgNP dispersions are generally obtained by methods of chemical decrease[18, 19]. The use of SDBS improves the distribution of AgNPs synthesized by an electrochemical process [50]. A pulsed sonoelectrochemical technique produced silver nanoparticles[11] in silver citrate and polyvinyl pyrrolidone (PVP).

The reduction in sodium borohydride in the presence of dodecanethiol causes silver nanoclusters of dependent size[12]. Radiolytic reduction in citrate and silver ions formed silver nanocrystallites, in which the size and shape of the solution depended on the citrate ions. Uniform silver nanowires are obtained by a polyol method that is another approach for the processing of large scales[54]. Silver nitrate reduction with alkaline-pH hydroxylamine hydrochloride produces stable, highly SERS-active, particle-size silver colloids of 23-67 nm [15]. A Tollen method used for the production of AgNPs resulted in an electrodeless deposition of silver of a measurement of 20-50 nm and a stable dispersal of the colloid in water or in undermonolayers[26].

Various experiments have been used in the silver soil synthesis with silver nitrate and sodium borohydride to increase the particle size from20–45 nm to 120–170 nm[17, 18]. Electroreduction in tetra-butyl ammonium salt containing acetonitrile silver ions developed 2-7 nm AgNPs in size. The effect of different electrochemical parameters on the final size of nanoparticles was studied via various kinds of counter electrodes[19]. The decreases of Ag+ by 1-hydroxyalkyl radical produced by 2-propanol radiolysis and β-irradiation by 1.0 to 10-4 M $AgClO_4$ solution resulted in the generation of long-term, colloidal silver shoals[10]. In the presence of polyethyleneimine AgNPs were developed in 7 nm size with unusual narrow Plasmon absorption band [61]. Monodispersed silver nanoparticles are synthesized in liquid phase using functional reverse AOT micelles and sized precipitation methods [12].

In the absence of light, the silver ions in ethanol are reduced with the nonionic surfactants in the solution [13]. Reverse micelles allow control of the size of nanoparticles of silver sulfide [14]. The agglomeration of the oligomeric clusters of silver atoms (Ag0, in Spanish) result in colloidal ag particles[25] by reducing various complexes with silver ions (Ag+). Spontaneous reduction of silver ions in the presence of nafion and the simple, air saturated 2-propanol solution is obtained by stable silver colloids[16].

4. MICROBE-ASSISTED SYNTHESIS OF NANOSILVER

4.1. Bacterial-Induced Synthesis.

Lactobacillus fermentum suppresses the growth of P. aeruginosa in the synthesis of biogenic nanoparticles[17] and monitors the development of biofilm. Bacillus flexus synthesized anisotropic nanoparticles formed spherical (12 nm) and triangular (61 nm) nanoparticles[18]. For the production of AgNPs using Bacillus cereus, an incubation period of 3 to 5 days is needed at room temperature[19]. The stability and synthesis of AgNPs rely on psychrophilic supernatants (Pseudomonas antarctica, Pseudomonas proteolytica, Pseudomonas meridiana, Arthrobacter kerguelensis, and Arthrobacter gangotriensis) or mesophil bacteria (Bacillus indicus and Bacillus cecembensis)[10] which are free from cell culture. Bacillus thuringiensis is the spore crystal mixture used to synthesize AgNPs of 15 nm of mixed (cubic and hexagonal) morphology[11].

The size of AgNP synthesized by Escherichia coli, Klebsiella pneumoniae, Escherichia coli, and Enterobacter cloacae that have effectively formed silver Nanoparticles [12, 13] is regulated by parameters such as temperature, pH, and $AgNO_3$ concentration. The 28-day association of Plectonema Boryanum UTEX 485 and aqueous $AgNO_3$ led to spherical silver nanoparticles being precipitated[14]. Within five minutes, the silver ions are easily reduced by adding Enterobacteriaceae cell filtrate (Escherichia coli, Klebsiella pneumonia, and Enterobacter cloacae) to the silver nitrate solution [15]. The size and shape of silver-synthesized nano-particles with microbes depend on the interaction between silver ions and bacteria [16, 17]. The silver-isolated Pseudomonas stutzeri AG 259 developed well-defined, silver nanoparticles and distinct morphology within the bacterial periplasmic space[18].

4.2. Fungal-Derived Synthesis.

Polydispersed spherical AgNPs ranging from 17 to 33 nm were synthesized using Helminthosporium tetramera cell-free filtrate and demonstrated strong antibacterial activity[19]. E. coli has been found to be more vulnerable than S. aureus to silver nanoparticles[80]. Humicola sp. thermophilic fungus reacted with Ag(+) ions, reduced the precursor solution and led to extracellular nanoparticulate formation[11]. In order to synthesize AgNPs from Aspergillus niger, ideal conditions such as temperature 37 to C, pH-6.0, and a 2.0 mM Silver Nitrate substrata concentration are needed [12]. In recent research, the patenting of research into microbial nanoparticle synthesis has also been increased. One such important work is the synthesis of AgNPs (5–50 nm) harnessing Trichoderma reesei fungus wet biomass at 28 to 1 hour after 120 hours of continuous shaking [13]. Bipolaris nodulosa was used to shape the spherical, semi-pentagonal and hexahedral structures (10–60 nm) of silver nanoparticles[84].

AgNPs made with Pleurotus sajor caju have strong antibacterial activity in comparison with Staphylococcus aureus on Pseudomonas aeruginosa and Escherichia coli [15]. The treatment of aqueous silver nitrate solution with fungus Fusarium semitectum[16] resulted in highly stable and crystalline silver nanoparticles (10–60 nm).

Extracellular mycosynthesis of AgNPs isolated from infected ginger formed by Fusarium acuminatum nanoparticles of 5 to 40 nm of size within 15 to 20 minutes. A nitratedependent reductase enzyme can reduce the silver ions and have shown effective antibacterial activity against Staphylococcus aureus, Salmonella typhi, Staphylococcus epidermidis and Escherichia coli[17]. Nanocrystalline

AgNPs of size 13–18 nm was developed using the 5 days of incubation with cell-free aqueous extract of Trichoderma asperellum[18].

Aspergillus flavus acquired silver nanoparticles in 72 hours on its cell wall, but was found to be released by ultrasound [89]. Rapid [Ag(NH3)2] + to Ag0 reductions occur when a quantity of -OH is inserted into the dried Aeromonas sp. SH10 cells [10]. Extracellular synthesis of the well-dispersed AgNPs of 5–25 nm of dimensions was achieved within a few minutes when Aspergillus fumigates were treated for silver ions [21]. The synthesis of silver nanoparticles supported by fusarium oxysporum led to agglomeration[22] whereas traditional halogent-tungsten lamp synthesis provided AgNPs with less aggregation within an hour.[23]

The reduction of silver ions occurs through the enzymes located on Verticillium surfaces and the cells multiply even after AgNPs have been formed[24]. The biomimetic conduit to plant species has been therefore developed through the microbially assisted synthesis of silver nanoparticles. The enzymes present in microorganisms reduce silver ions that form silver nanoparticles [25]. These species are vulnerable to increased silver ion concentrations[26]. There are also some problems with nanosilver, which is synthesized by a microorganism, when used in biomedical applications.

5. CONVENTIONAL METHODS OF NANOPARTICLE SYNTHESIS:

A critical picture the exploitation of reduction agents in the synthesis of nanoparticles has opened a critical road to environmental protection and also restricted the use for biological applications of these noble materials. The use of dangerous chemicals and the amount of money involved in the synthesis process contributes to a thorough energy process that eliminates the environmental friendliness of the traditional methods[17–22]. Chemical synthesis of silver colloids contributes largely to aggregation as the storage time increases[2]. The above problems have suggested the incorporation of the principles of green chemistry into the synthesis of metal nanoparticles. The key components for green nanosynthetic routes are environmentally friendly solvents and reducing and stabilizing agents[13].

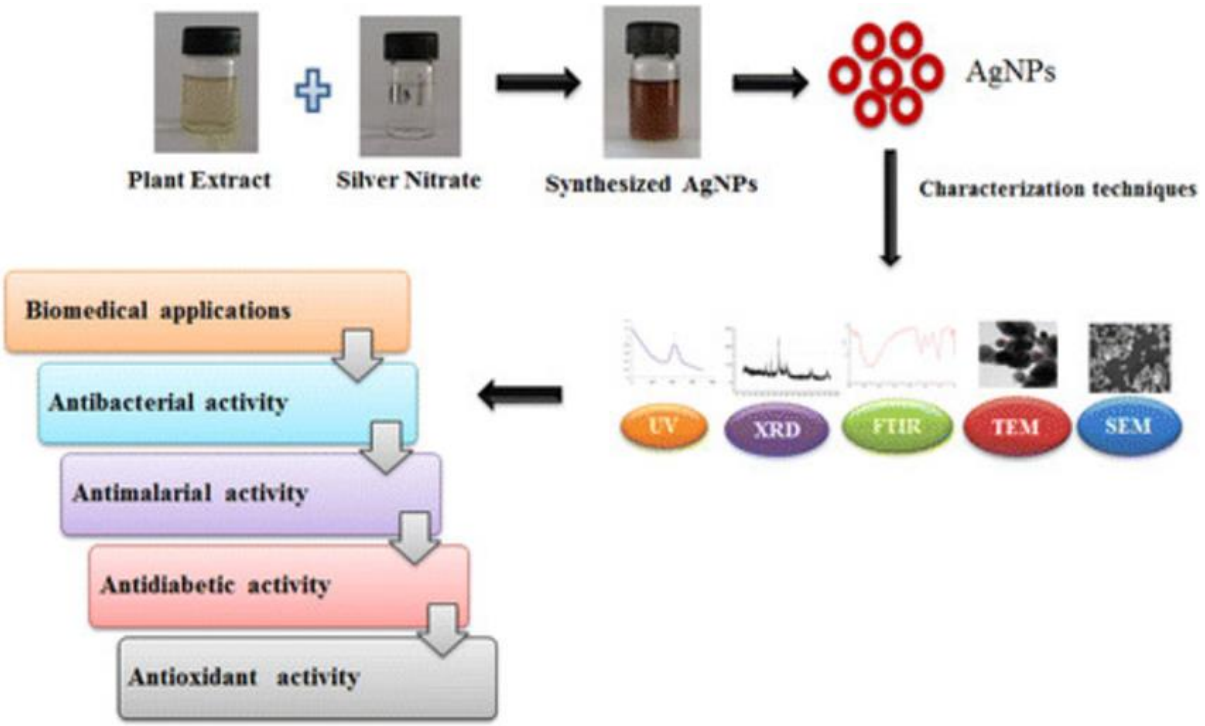

Fig 3.

6. PLANT-MEDIATEDSYNTHESIS

Extracts of Myrmecodia pendans (10–20 nm) [14], Tectona grandis (30–40 nm) were used to obtain nanosilver of different sizes. [15], Cumini Syzygium, (10–15 nm); Rhynchotechum ellipticum (51-73 nm) [16]. Alternaria alternata (27–79 nm) Alternaria alternata [18] Citrus maxima (2,5–5,7 nm) [19], Desmodium gangetum (18-39 nm) [10], Thevetia peruviana latex (10–30 nm) [111], Lycopersicon esculentum Mill (30–40 nm) [39], Desmodium gangeticum (18–39 nm) Piper pedicellatum [12] (2-3 nm) [13], Asian Centella L. (30-50 nm) [13] [14], Bozwellia serrata, Triphala [115], Neem leaves (59 nm) [116] Ocimum sanctum leaf [17], Pomegranate seed (30 nm) [18], Piperite mentha (90 nm) [19], Coenigi murraya (10–25 nm) [18], capping substances, etc.

Depending on the type of extracts and the method of preparedness, the size of silver nanoparticles synthesized using antioxidants made of blackberry, blueberry, granates and turmeric extracts was developed between 20 and 500 nm [11]. P. maderaspatensis was a good catalyst for the reaction initiation, which quickly produced AgNPs with particles as small as 59 nm within

24 hours[12]. AgNPs synthesized by Delonix elata after 24 h incubation display a zeta-potential (−18 mV) value [13]. Thin, large-scale AgNP films were obtained using the SILAR method for guava leaves extract [14]. AgNPs were developed using banana stem extract from different forms, such as truncated octahedron, rhombic dodecahedron, cube, octahedron and octogon structures, which had particle size ranging from 75.50 nm to 1.22 μm [15].

AgNPs were synthesized with the Potamogeton pectinatus L and continuous growth occurred as concentrations of silver nitrate were increased, leading finally to polydispersion [16]. Rich extracts of Rumex hymenosepalus polyphenol assisted synthesis provided a mix of cubic facial-centered and hexagonally shaped AgNPs of 2-40 nm of size[17]. The optimized conditions for the fast synthesis of Cissus quadrangularis mediated silver nanoparticles [18] are stated to be high pH and temperature. The key cause of the reduction of silver ions to AgNPs was water-soluble organics in plant materials[19]. For AgNPs synthetized with Prunus armeniaca fruit extract (apricot) in DPPH and ABTS tests, almost 50 percent free radical scavenging activity was observed [10].

Needle shaped AgNPs with a size of 82.46 nm were obtained from the Coleus forskohlii root extracts[11]. It has been found that Malva parviflora produces monodispersed AgNPs in less time than the Beta vulgaris, Anethum graveolens, Allium kurrat and Capsicum frutescins[12]. Water-solvent compounds such as saponins found in a Memecylon edule leaf extract have been shown to be responsible for reducing silver ions under incubation at 150 rpm in a dark shaker, forming primarily square shaped AgNPs between 50 and 90 nm [13]. Sphere-shaped AgNPs (average size 18.2 ± 8.9 nm) were produced with Vitex negundo methane leaf extract and demonstrated against both Gram positive and Gram-negative bacteria antibacterial activity[14].

The change in the size distribution and the decreased synthesis of AgNPs in protein deprived fractions indicated that Chlamydomonas reinhardtii cell proteins have been involved in the biosynthesis of AgNPs[15]. The extracts from the tissue culture of the marsh plant Sesuvium portulacastrum L., extracted from callus and leaves, have been used for AgNP synthesis and stabilized by polyvinyl alcohol[16]. The reduction of AgNO3 by eugenol in the clove extract takes place because of the inductive effect of methoxy and allyl groups in the ortho and proton-releasing-OH Group positions of one eugenol molecule. Following this, the resonant structure develops in the anionic form of eugenol[17].

The heterocyclic polyol and water-soluble components present in the Cinnamomum camphora leaf broth are decrease of silver ions[13]. The bifunctional tripeptide (DDY-OMe) in Chlorella vulgaris Asp residues, with one Tyr residue and two carboxylic groups, produces small Ag nanoplates of good yield [19]. Emblica officinalis extract[10] was used to make highly stable silver and gold nanoparticles in sizes 10–20 nm and 15–25 nm, respectively. The removal of the metal ions made easier by the reduction of sugars and terpenoids in the leaf broth Azadirachta indica[11] constituted pure silver, gold, and bimetallic nanoparticles.

7. VARIOUS METHODS OF SYNTHESIS OF SILVER NANOPARTICLES

A variety of methods for synthesizing silver nanoparticles are used. A detailed investigation of the literature discovered various methods of manufacturing silver nanoparticles.

7.1. Synthesis at Room Temperature.

Applying the agnthera dentatum, nanoparticles were generated at room temperature within 10 minutes and nanoparticles were shown to have antibacterial activity at a 50-ppm concentration against E. coli, P. aeruginosa, K. pneumonia and E. faecalis [14]. The flavonoids and proteins in the leaf extract from Tephrosia purpurea are the most important factors for AgNP formation. AgNPs were found to be 16 nm in size, with the XRD results in good agreement[13]. In 10 min by reducing silver ion by an aqueous extract of Alternanthera sessilis, the AgNPs (30 nm) were produced and it was found that the proteins and ascorbic acid are responsible for the synthesis[14].

AgNPs synthesised by using Mangifera indica, Eucalyptus teretikornis, Carica papaya, and Musa paradisiaca leaf extracts, at ambient temperatures, resulted in various shapes and dimensions: 50-65 nm (ovular), 60-150 nm (oval), 25–40 nm, and 10-50 nm, respectively (round and irregular)[145]. The total reduction of silver ions by aqueous Padina tetrastromatica extract was observed at room temperature 72 hours after shaking [16].

In the synthesis of silver nanoparticles 10–70 nm in size [17] environmental benign aqueous extract of A. dubius was used as an efficient capping and reducing agent.

Rapid synthesis by a bryophyte, Fissidens minutus, of silver nanoparticles was obtained during room temperature [18]. Metallic agnps (10 nm) were produced at room temperature with aqueous sorghum extract within a few minutes [19]. AgNP (20 nm) and hexagonal (10-50 nm) shapes were derived from Argemone mexicana extract at room temperature after 4 hours and found to be extremely toxic to pathogenic bacteria and fungi at 30 ppm[10]. Cubic AgNPs 50-150 nm is synthesized by the Aquatic Solution of Silver Nitrate (AgNO3) using the Eucalyptus Hybrid Leaf Methanolic Extract at ambient temperature[11]. The polydispersed AgNPs (5–30 nm) were produced by reducing the use of Mentha piperita silver ions within 15 minutes at room temperature [12].

7.2. Synthesis at Higher Temperature.

The silver ions were reduced to AgNPs by heating for 20 min the root aqueous extract mix of Withania somnifera and the aqueous Ag(NO3)2 with 60–80 livres C [13]. Comparative studies of several Amaranthus polygonoides methods in AgNP syntheses showed higher

temperature results in fast synthesis[14]. The visibility of prominent reddish-brown color was observed at 60 to C within 20 minutes, indicating the development of Agnihotra with the use of marine Gracilaria corticata algae [15]. The reduction capacity of Cacumen platycladi to reduce sugars and flavonoids was increased at 90 to C and leads to the formation of AgNPs (18.4 nm) with a small distribution of sizes[16].

The 0.25 M AgNO3 solution for Cycas leaf extract solution was maintained on the steam bath for 10 min, developed spherical form AgNPs with a diameter of 2–6 nm[17]. Continuous stirrings of Allium cepa Silver nitrate Extract 50-60 by C resulted in medium-sized AgNPs (33.6 nm), with complete E. coli and Salmonella typhimurium inhibition at 50 μg/mL [18]. Nanosilver 10–20 nm was developed for 4 h in an oil bath with constant mixing for silver nitrate and latex from Jatropha curcas [19]. The temperature increase to 95 pounds C reinforces the reaction of Magnolia kobus leaf broth and silver nitrate, which yield agNPs up to 90 percent within 11 minutes [10].

7.3. Synthesis Using Microwave Irradiation

Citrus fruit scales (green, grapefruit, tangelo, lemon and lime), used to synthesize microwave-assisted AgNPs showed orange peel extract to provide silver nanoparticles in 15 minutes compared to other extracts [11]. Sphere-shaped AgNPs of 15–20 nm synthesized with microwave irradiation with Acacia farnesiana (sweet acacia), showed a stronger inhibitory activity against E. coli, S. aureus, B. subtilis, and P. aeruginosa [12].
Cuminum cyminum seed and silver nitrate solution ratio 1: 10 radiated to AgNP for 120 seconds in a domestic microwave [13]. A microwave-assisted AgNP synthesis was obtained by an extract of Cymbopogon citratus at 8.0 pH in 8–10 min when it is irradiated to 90 watts [14]. In order to reduce silver ions to silver nanoparticles, microwave irradiation is best considered. This process produces smaller, uniformly distributed particles [15].

7.4. Synthesis by Sonication.

In comparison to room and higher temperature conditions, rapid synthesis of silver nanoparticles using portulaca oleracea was observed in sonicative process and found to be less than 60 nm[16]. Due to the acceleration effect in chemical dynamics and reaction speeds, AgNPs derived from Pisonia grandis were found to be consistent in sonicity. Ultrasonic energy may have interfered with the chemical synthesis route by producing free radicals[17].

7.5. Light Induced Synthesis.

Poly-dispersed silver pellets 8–10 nm was quickly synthesized with Cynodon dactylon leaf extract under sunlight from aqueous silver nitrate[18]. Solanum trilobatum Linn extract was used to improve the antidandruff effect against mushroom pathogens (Pityrosporum ovale and Pityrosporum followulitis)[15–20 nm) in the sunlight and mixed with shampoo. AgNPs decreased significantly to around 10–50 nm by irradiation of silver nitrate and euphorbia miliisolution with xenon lamps after ultrashort laser pulses[10].

8. PHARMACOLOGICAL APPLICATIONS

8.1. Antimicrobial Activity.

The highly powerful antibacterial activity of Silver Nanoparticles synthesized by Abutilon indium leaf extract was seen on Staphylococcus aureus (16.8 mm), Bacillus subtilis (18.3 mm), Salmonella typhi (14.5 mm) and Escherichia coli (17.2 mm) [11].

The Ipomea carnea-AgNps impregnation with cellulose acetate membrane was structured into a 14 mm area of Mycobacterium smegmatis inhibition[12]. Flavobacterium branchiophilum was more sensitive than the two other fish bacterial pathogens Aeromonas hydrophila and Pseudomonas fluorescens[13], shown by the mediated AgNPs from Boerhaavia diffusa. ANPs with Lingoberry and Cranberry Juices supported against S. aureus, B. subtilis and B. cereus have been found to be more active and to be less active in combating C. albicans and food borne by B. cereus[14].

Inflorescence Cocos nucifera was greatly inhibited by the growth of V. alginolyticus, K. pneumoniae, P. aeruginosa, B. subtilis, and P. shigelloides. Microscopy reveals the binding nature of AgNPs to the bacterial cell wall [15]. AgNPs synthesized with lemon peel extract demonstrated maximum inhibition zone 12 ± 0.3SD, 11 ± 0,5SD with T. mentagrophytes and C. albicans, respectively, and no T. rubrum activity[16]. A stronger antibacterial activity against Escherichia coli (12 mm) and Pseudomonas aeruginosa (18 mm) was observed by Triangular, Hexagonal and Sphere AgNPs between 78 nm and 98 nm of leaf-extracts of Caesalpinia coriaria[17]. P. oleracea-mediated AgNPs can result from C. albicans and S. cerevisiae apoptosis due to the generation of reactive oxygen species and the decreased hydroxy radical development initiated by phytoconstituents capped in synthesized AgNPs[18].

In vivo study of biochemical and histological parameters shows that AgNPs synthesized using Leucas aspera have antibacterial effect on fish models (Aeromonas hydrophila and Catla catla) [19]. Sphaeranthus amaranthoides synthesized silver nanoparticles have been shown to improve antimicrobial activity as a result of destabilisation of the external membrane, preventing bacterial breathing and depletion of ATP intracellular contributes to denaturation of the cell wall of the bacterial cell. The difference in the inhibition of growth in Gram + V and Gram − V bacteria may be caused by cell membrane permeability [10]. AgNPs synthesized using leaf extract from vinca rosea showed promising inhibition at 10 μL concentration of Staphylococcus aureus, Lactobacillus, Escherichia coli and Pseudomonas fluorescens[11].

AgNPs synthesized using Solanum Xanthocarpum berry methanol extract suggest stronger anti-H. pylori activity and non-competitive inhibition from Lineweaver-Burk plots [15] have been concluded. Desmodium triflorum nanoparticles helped to inhibit growth of

Staphylococcus and E. coli by 62% and 88% respectively at 24-hour concentrations of 14–60 mg/cm3, while 100 µg/cm3 showed almost 100% inhibition[16]. Gelidiele acerosic extract Synthesized AgNPs are highly active in fungal species with a concentration of 50 µL, compared to the normal antifungal agent clotrimazole (17) against Mucor indicus (22,3 mm) and Trichoderma reesei (17,2 mm)

For Ocimum sanctum leaf extract helped AgNPs for Proteus vulgaris and Vibrio cholerae the maximum inhibitor zones (25 and 27 mm) were observed. The Vitex negundo leaf extract nanoparticles showed a minimum rate of inhibition against the abovementioned bacterial pathogens[18]. Silver nanoparticles with leaf broth Gliricidia sepium showed 3 mm of Staphylococcus inhibition area and 2 mm with Escherichia coli, Pseudomonas aeruginosa and Klebsiella pneumonia at concentration of 50 µL[19].

8.2. Larvicidal Activity.

The maximal effectiveness of LC50 values for Leucas aspera assisted synthesized AgN Ps was 8.5632, 10.0361, 14.4689, 13.4579, 17.4108 and 27.4936 mg/L and LC90 values 21.5685, 93.03928, 39.6385, 42.2029, 31.3009 and 53.2576 mg/L, respectively, against 4th A. aegypti instar larvae [190]. AgNPs synthesized with Drypetes roxburghii (wall.) showed 100% mortality in second instar Anopheles stephensi larvae at 5 ppm and 100% mortality in all Culex quinquefasciatus and Anopheles stephensi instars, respectively, at double concentrations [11]. AgNPs 25 – 30 nm synthesized with the aqueous nerium oleander leaf extract was shown to have the highest mortality against both larvae and Anopheles stephensi pupae [12].

The larvae were exposed to various Pedilanthus tithymaloides-AgNP concentrations and demonstrated 100% mortality from the first to the fourth sample and A. aegypti pupae after 24 hours. AgNPs have been detected as a lethal concentration (LC50) of 0.029, 0.027, 0.047, 0.086, and 0.018 percent, without control mortality, for larvae and pupal stages[13]. Significant activity against the vector mosquitoes A. stephensi, A. aegypti and C. quinquefasciatus was reported to be reported for synthesized AgNPs with Sida acuta[14]. The IC50 values for the antiplasmodial activity of the AgNPs synthesized with the use of aqueous Ashoka and Neem extracts are 8 and 30 µg/mL for Plasmodium falciparum, respectively[15].

In Poecilia reticulata after 24, 48, and 72 h exposure, Vinca rosee synthesized AgNPs showed noticeable toxicity, but have a potential to control A. stephensi and C. quinquefasciatus[16]. The highest larval mortality values of LC50 against larvae and pupae were shown by the euphorbia hirta synthesized agnp [17]. The adulticidal and larvicidal operation of C. quadrangularis synthesized AgNPs was 100% mortal against H. maculata and R.(B.) microplus[18]. According to the study, Anopheles subpictus and Culex tritaeniorhynchus have significant larvicidal activities of synthesized AgNPs using the aqueous extract of Eclipta prostrata[19].

8.3. Anticancer Activity.

Silver nanoparticles synthesized with Acalypha indica Linn display a cell inhibition of human breast cancer cells (MDA-MB-231) of just 40% [20]. The 50% viability of MCF-7 cells at 5 µg/mL for Dendrophthoe falcata (L.f) Ettingsh [21] agNPs is lost. Nanoparticles made from Sterculias foetida (L.) seed extract demonstrated a cellular fragmentation of the DNA against the HeLa carcinoma cell lines [22].

After 24 h incubation, the Datura inoxia-AgNPs inhibited 50 percent proliferation of the human breast cancer cell line MCF7 by stopping cells cycle phase development and reducing the DNA synthesis to inducing apoptosis, at 20 µg/mL[23]. The cytototoxic tests of Chrysanthemum indicum-AgNPs demonstrated no toxicity to 3T3 mouse embryo fibroblast cells at 25 µg/mL[24].

For AgNPs synthesized using phytolacca decandra, Gelsemium sempervirens, Hydrastis canadensis and Thuja occidentalis, variations in their degree of anticancer activity against A375 skin melanoma cells were observed[25]. AgNPs derived from ficus religiosa were successful in 50 µg/mL against the mice induced by DAL model (30–35 g) [26]. Dosage-dependent response of silver nanoparticles synthesized with Origanum vulgare to human lung cancer A549 (LD50–100 µg/mL) [27]. Full apoptosis (95%), with 25 µL/mL Alternanthera sessile supported AgNPs for prostate cancer cells (PC3) was observed, whereas a 99% breast cancer cell growth inhibition (MCF-7) was obtained [28].

Albizia adianthifolium leaf extract synthesized agNPs (AAAgNPs), showed a cell viability of 21% and 73% for A549, and a typical peripheral lymphocyte of 117% and 109% for the exposure to 10 µg/mL and 50 µg/mL, respectively, after 6 h exposure. This shows that the AgNPs are not harmful to normal PLs[29] cells. A549 cells were obtained at 43 µg/mL from AA-AgNPs with 50% inhibition cell and induces ROS death resulting in apoptosis[21]. For MCF-7 cells treated with Sesbania grandiflora mediated AgNPs (20 µg/mL) after 48h in Hoechst staining, nuclear condensation, cell shrinkage and fragmentation are observing. These modifications suggest that the cleavage of the substrates leads to activation of the DNA repair [21]. There has been a cell death (100 per cent) of HeLa cell line with 100 µg of AgNPs synthesized with Morinda citrifolia root [22]. Longer exposures to Eucalyptus chapmaniana AgNPs (0.02 mmol/mL) caused 85% cell death after an incubation of 24 hours [23]. The viability of A375 cells (50 percent) is found at different levels of AgNPs, synthesized by Phytolac decandra, Gelsemium sempervirens, Hydrastis canadensis, and Thuja occidentalis [205]. AgNPs made of Aloe, Magnolia, and Eucalyptus leaves extracts at 2 to 4 ppm concentrations have been found noncytotoxic to human embryonic kidney 293 cells, as analyzed by automated InQ Plus device[24].

After 6 h of treatment with Rosmarinus officinalis-AgNPs 2 mM, the viability of HL-60 cells was reduced to

44% and cell mortality increased to 80% following 24 h of incubation. Cytototoxicity was extremely sensitive to the dimensions of the nanoparticles formed with the herb leaf of Iresine and the measurements of viability decreased with increased doses of HeLa cell line [26] (25–300 µg/mL). The synthesis of silver nanoparticles can be caused by piperidin, piperlongumine, and piperlonguminine in Piper Longum which have a major cytotoxic effect (94.02%) at 500µg/mL on HEp-2 lines [28]. The Euphorbia nivulia stem latex capped AgNPs solubilizes AgNPs into water and serves as a bio-consistent vehicle for carrying nanosilver to human carcinoma (A549)[218]. Aloe Vera-conjugated AgNPs treated with HRDF cells were not shown to be cytotoxic, but have good antibacterial activity in E. coli even at very low levels[29].

8.4. Wound Healing Activity.

The bacterial growth of Escherichia coli, Pseudomonas aeruginosa, and Staphylococcus aureus has been impeded by silver nanoparticles synthesizing in situ in a network of peptide fibers using UV radiation. AgNPs containing HDFa cell hydrogels showed no substantial cell viability influence[20]. AgNPs extracted from the extract root of Arnebia nobilis for wound healing in the excision animal model have beneficial effects on the antimicrobial ability of the animals and have provided a novel therapeutic guideline for the treatment of wounds in clinical practice[21]. Indigofera aspalathoides mediated AgNPs were studied after an excision in animal models for wound-healing applications [22]. AgNPs extracted from Chrysanthemum morifolium applied to a clinical ultrasound gel used on an ultrasound probe showed a bactericidal behavior that contributes to the instrument's sterility[23].

In the in vitro analysis of the Acticoat Flex 3 dressing based on AgNP, it was found that agNPS significantly reduce mitochondrial activity and cellular staining techniques display nuclear integrity with no signs of celular death[24].

Applying it to a 3D fibroblast cell culture and to a real partial burning patient. AgNPs lead to the distinction of fibroblasts into myofibroblasts, thus improving the effectiveness of wound healing[25]. The decrease in wound inflammation with regulation of liver and kidney functions was observed during the skin wound healing with its antimicrobial properties as the positive effects of silver nanoparticles [26]. AgNPs play a role during wound healing in dermal contraction and in epidermal reepitheliation, thus leading to an increased wound closure rate[27].

AgNPs made extracellularly with the fungus Aspergillus niger are reported to modulate cytokines involved in the excision rat model wound healing [228]. An average 3.35 days reduction was observed in wound healing for the agnp integrated into the cotton fabric and dressings and also improved bacterial clearance from contaminated wounds without any adverse effects[29–30]. Silver nanoparticles have antimicrobial properties that reduce the inflammation of wounds and modulate fibrogenic cytokines[19].

8.5. Medicinal Textiles and Devices.

AgNPs made from cotton cloth, synthesized by A. dubium and transpiratory pad samples showed high resistance to sweat bacterium Corynebacterium[27]. Antimicrobial activity against Pseudomonas aeruginosa has been shown by the antibacterial activities of gauze cloth discs incorporated in AgNPs formed by green mature thalli Anthoceros[28]. The minimum bactericidal concentration for Escherichia coli BL-21 strain exhibits curcuma longa tuber powder capped silver nanoparticles at 50 mg/L. The immobilization of cotton cloths with sterile water has shown improved bactericidal efficacy compared to immobilized polyvinyllidene fluoride cloth [29]. The introduction of Azadirachta indica into cotton fabric contributes to antibacterial effects against E. coli[20].

9. MISCELLANEOUS APPLICATIONS

Manilkara zapota extract mediated agnp synthesis and exhibited acaricidal activity with Rhipicephalus microplus at LC50 3,44 mg/L[21]. AgNPs synthesized with the extract of Jatropha gossypifolia demonstrated higher levels of amebicidal activity against Acanthamoeba castellanii [22]. The nonlinear coefficient of refraction and absorption of AgNPs synthesized using the Z-scan technique, with the ns laser pulses, was superior to the optical nonlinearity compared to the coriandrum sativum extracts synthesized using other methods [23].

9.1. Water Treatment.

Stable agNPs synthesized using the Anacardium occidentale fresh leaf extract in tap water at 80 to C bud as a novel sensing probe [Cr(VI)] for chromium ions[24]. Bacteria decreased when 100 mL of water was treated after 6 h and increased when the concentration of silver nanoparticles made with Prosopis juliflora leaf extract (10 mg) increased with increasing incubation times [25].

9.2. Catalytic Activity.

In reducing Methylene Blue (MB) by NaBH4, the size depends on the catalytic activity of the synthesized AgNPs using Kashayam, Guggulutiktham [26]. In contrast to glassy carbon and metallic Ag electrode, Acacia nilotica pod mediated AgNP's edited glassy carbon electrode has demonstrated higher catalytic activity in reducing benzyl chloride[27]. Spectrophotometrically, photocatalytic degradation of methyl orange has been calculated using Ulva lactuca synthesized AgNPs under visible illumination as a nanocatalyst [28]. The synthesized AgNPs with Gloriosa superba extract work through the effect of electron relays and effect the degrade of methylene blue at the end of the 30 minutes [29]. The excellent catalytic activity of polydisperged silver nanoparticles developed using triticum aestivum(khapali ghahu) extracts[20] is rapidly reduced by hydrogen peroxide. The reduction in the presence of Breynia Rhamnoides-AgNP and NaBH4 from 4-NP to 4-aminophenol (4-AP) is performed effectively and has been determined to rely on the size of nanoparticles or the stem extract concentration[21].

10. RECENT TECHNIQUES IN THE SYNTHESIS OF NANOPARTICLES

10.1. Pulsed Laser Ablation Techniques.

Compared to other physical and chemical techniques, it is a basic technique used in the production of nanomaterials such as noble metals, alloys, oxides and semiconductors. This approach focuses on the surface of the target material submerged in the Liquid, and the production of a pulsed laser. Pulsed laser ablation in liquid (PLAL) is characterized primarily by the development in one stage of well described nanoparticles without any subsequent thermal treatment [22–24].

Scale of AgNPs of between 15.1 and 4.3 nm were synthesized with a laser removal of the Ag target from deionized water at a relatively high laser fluence of 15 J/cm2, which increased linearly with a rise in the thickness of the water layer and a maximum value of 14 mm [25]. AgNPs were developed by means of a removal of a pure Ag plate for 30 minutes using A Q-Switched Nd: YAG pulsed laser (ти = 532 nm, 360 mJ/pulse) in the organic compound (ethylene glycol) and biopolymer (chitosan), respectively[26]. For the synthesis of AgNPs (6–12 nm), laser ablation was used for high pure silver bulk in distillated water by maximizing the effect of laser fluid[27]. Fragmentation of AGNPs was shown to be highly efficient at 355 nm Laser Light absorption, synthesizing the ablation by laser (Nd: YAG, т = 1064 nm) of a silver target immersed in different NaCl solutions as well as the water concentration showed[28].

11. CONCLUSION

The above overview covers the numerous methods for the synthesis and range of applications of silver nanoparticles. The analysis highlights plant-assisted synthesis research work on AgNPs, an emerging area in the field of nanotechnology. The steady rise in publications on the above-mentioned subject was discussed in the interests of future researchers. With these exotic silver nanoparticles, new insights into pharmacological applications such as anticancer, larvicidal, medical textiles and equipment are gleaned. These biogenic silver nanoparticles would therefore make a major contribution to the field of bio nanomedicine.

Conflict of Interest: None Declared

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