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Synthesis paradigm and applications of silver nanoparticles (AgNPs), a review

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ABSTRACT

Nanoscience is an inspiring and influential discipline of science which have accessible numerous novel and cost-effective yields and applications. Currently, nanotechnology research has been empowering more in agricultural sector, food process and medicinal industries. The surface area to volume ratio of nanoparticles is quite large which have 1–100 nm size. Nanomaterials have superior bioavailability than larger particles, resulting in greater utilization in single cells, tissues and organs. Referable to the growing demand of nanoparticles, it is essential to build up synthetic method which is profitable, environmentally sustainable and which can substitutes with effective and competent technology to synthesis environmentally benign nanoparticles (NPs). Nanomaterials are “deliberately engineered” to direct the enhancement of special properties at the nanoscale. Nanoparticles have been known to be used for abundant physical, biological, and pharmaceutical applications. Nano-silver is the most studied and utilized nanoparticle. Silver nanoparticles (AgNPs) have been the topics of researchers because of their unique properties. Thus, this review presents various synthesis methods of AgNPs and its application in different sectors.

1. Introduction

In science and engineering, sustainable nanotechnology is successful in giving solutions for the challenges in various sectors such as medicine, catalysis, industrial and agricultural activities [1]. Nanostructures are the issue of involvement for all applications of Nanotechnology anywhere in nature and dimension of the nanoparticles (NPs) decides their feature properties [2]. It is broadly accepted in the background of nanoscience and nanotechnologies, focus on the units of size, rather than of any other unit of scientific measurement [3, 4]. Nano-sized particles are unique matter which falling in between the microscopic and mesoscopic. When compared to the dimension of nanoparticles with other “small” molecules, called the bacterium is large in contrast which have a high surface area to volume ratio and a high fraction of surface molecules. They have definite physicochemical properties such as optical property [5–9], magnetic property [9], catalytic property [10], antimicrobial property at the nano-stage [8–10] which characteristically consequences in superior chemical reactivity, biological activity, and catalytic behavior compared to larger particles of the identical chemical composition [3, 4]. Nanomaterials are “deliberately engineered” to guide the improvement of special properties at the nanoscale. Nanomaterials may have superior bioavailability than larger units, ensuring in greater utilization of individual cells, tissues, and organs [9]. Nanomaterials that gain admission to our bodies just penetrate biological membranes and access cells, tissues, and organs. Materials with size 300 nm can be taken up by individual cells while nanometers, that quantify below 70 nm can still use up by our cells’ nuclei, where they can cause principal damage [3, 10].

Metal NPs are holding from small number of atoms to numerous metal atoms, stabilize by ligands, surfactants, polymers or dendrimers defensive their surfaces. They play a vital role in catalysis as they imitate metal surface activation and nanoscale increase efficiency to heterogeneous catalysis [3, 5]. This method is likewise applicable to homogeneous catalysis, for the reason that there is a wide range among tiny metal clusters and bulky metal clusters, the end being also called colloids, sales or NPs [11].

Biosynthesis of metal, metal oxides and metal composite of nanoparticles are cleaner, nontoxic, and environmentally benign than the physical and chemical methods. Nowadays, metal based nanoparticles are synthesized for numerous applications from different plant parts.

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such as leaves, roots, flower, seeds etc. For instance, Cu/Fe3O4 nanoparticles from Sillybium marianum L. Seed extract [12], Cu/reduced graphene oxide/Fe3O4 nanocomposite from Euphorbia wallichii leaf extract [13], Gold nanoparticles (AuNPs) from Anthemis xylolopa flowers aqueous extract [14], Palladium nanoparticles from the Hippophae rhamnoides linn leaf extract [15], Pd/Fe3O4 nanoparticles from Euphorbia condylarca M. bieb root extract [16], Palladium nanoparticles (PdNPs) from Sour Cherry tree Gum [10], Copper nanoparticles supported on bentonite (bentonite/CuNPs) from Thymus vulgaris L. leaf extract [17], Pd nanoparticles supported on graphene oxide from bafter fruit extract [18], Natrolite zeolite/Pd nano composite using Piper longum fruits extract [19], Cu/reduced graphene oxide (RGO-Fe3O4) using nanocomposite Berberis vulgaris fruit extract [20], CuO nanoparticles by aqueous extract of Anthemis nobilis flowers [21], AuNPs by Anthemis xylolopa flowers [22], CuNPs using Ginkgo biloba L. leaf extract [23], PdNPs using Euphorbia thymifolia L. leaf extract [24], CuNPs using Euphorbia esula L. leaves extract [25], PdNPs using Hippophae rhamnoides linn leaf extract [15], Pd/Fe3O4 nanoparticles using Euphorbia condylarca M. bieb root extract [26], Au/Pd bimetallic nanoparticles from Euphorbia condylarca M. bieb [27], biosynthesis of AgNPs for application Ag/bone nanocomposite Myrica gale L. extract [28], Ag/RGO/Fe3O4 using Lotus garrcini leaf extract for nano-catalyst [29], AgNPs using Gongronema latifolium leaf extract [30], green synthesis of PdNPs using Salvia hydrangea extract for catalytic reduction of dyes [31], green synthesis of AgNPs supported on waste peach kernel shell using Achilea millefolium L. extract [32], synthesis of Ag/Fe3O4 nanocomposite using Euphorbia peplus Linn leaf extract [33], and synthesis of Pd/perlite nanocomposite using Euphorbia nertifolia L. leaf extract [34].

Silver is a transition metal in one set with Copper and Gold which is a soft, white, lustrous element possessing high electrical and thermal conductivity. It has been known extensively due to its medical and therapeutic benefits before the recognition that microbes are agents for infections. It is practiced in many forms as coins, vessels, solutions, foils, sutures, and colloids as lotions, unguents, and thus onwards. The medical properties of silver have been familiar to have strong inhibitory and bactericidal effects before the recognition that microbes are agents for infections [3,11]. It tends been familiar to have strong inhibitory and bactericidal effects that exert considerable as a wide spectrum of antimicrobial activities [8-10]. The mechanical grinding of bulk metals and subsequent stabilization of the resulting nanosized metal particles by the addition of colloidal protecting agents are some examples of the top-down method. Besides the bottom-up method, include the reduction of metals, electrochemical methods, and decomposition [7,9]. In this section, we introduce the overview preparation of silver nanoparticles using physical, chemical, and biological synthesis is highlighted.

2.1. Physical methods

The most important physical approaches are evaporation-condensation and laser ablation [37,38]. The absence of solvent contamination and the homogeneity of NPs distribution are the compensation of physical synthesis methods in contrast with chemical processes. Tube furnace syntheses of silver NPs at atmospheric pressure has some disadvantages such as energy consumption, slow synthesis and call for high concentration [39]. Laser ablation of metallic bulk materials can be synthesized AgNPs in solution. Depends upon various factors, including the wavelength of the laser interrupting the metallic target, the period of the laser pulses, the ablation time extent and the efficient liquid medium, with or without the existence of surfactants, and the laser power are some of the factors which determine the ablation effectiveness and the characteristics of synthesized nano-silver particles [39,40]. From available methods, Laser ablation is a unique and significant method which results pure and clean metallic nanoparticles without using chemical reagents in solution [37,38].

2.2. Chemical method

2.2.1. Chemical reduction

Chemical reduction is the most common approaches for the synthesis of AgNPs using organic and inorganic reducing agents. This is by continuing through a single process to generate a colored silver solution, this is due to the surface of a metal having free of charge electrons in the conduction band and positively charged nuclei. Then, the formation of long-lived clusters of silver is formed and confirms the synthesis of AgNPs [41]. In general, one-pot method of reduction of AgNO3 using different reducing agents such as sodium citrate, ascorbate [9], Sodium borohydride (NaBH4) [7,38,41], elemental hydrogen, poloyr process, N,N-dimethylformamide (DMF) [38,41], Ascorbic acid, poly(ethylene glycol)-block copolymers [10], hydrazine, and ammonium formate [41] are applied for reduction of silver ions (Ag+) in the aqueous or nonaqueous solution [38].

2.2.2. Microemulsion techniques

Microemulsion technique has various applications in chemical and biological field due to their exceptional properties such as, ultralow interfacial tension, huge interfacial area, thermodynamic constancy and the capability to solubilize immiscible liquids [42]. The Microemulsion method assures to be one of the flexible preparation techniques which allows to organize the particle properties such as mechanisms of particle size control, geometry, morphology, homogeneity and surface area [42,43].

2.2.3. Microwave-assisted synthesis

A microwave synthesis engages the reduction of silver nanoparticles with changeable rate microwave radiation in opposition to the conventional heating technique [44]. The technique gives up a more rapidly reaction and gives a higher concentration of silver nanoparticles with the same temperature and exposure [7,42,44].

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3. Green synthesis of silver nanoparticles (AgNPs)

The growth of an easy, profitable, reliable and eco-friendly approach for the synthesis of nanomaterials is an important aspect of nanotechnology [44–46]. There is a growing need to develop an environmental friendly nanoparticle synthesis process that does not use noxious chemicals. The conventional physical methods normally give up low quantity of AgNPs, and chemical methods are considered to be noxious and consume a lot of energy. Consequently, the spreading out of an environmentally benign method for synthesizing metallic nanoparticles is an inevitable practice in the field of nanotechnology [46–48]. Green synthetic systems using any biological microorganisms such as bacteria, fungi (yeast) and plant extracts [7,42,44,45]. Even though chemical and physical methods, possibly will effectively fabricate pure and well-defined nanoparticles. These methods were quite expensive and potentially hazardous to the surroundings. Utilization of biomass such as microorganisms, plant extract could be an option to chemical and physical methods for the production of nanoparticles in a green manner [41,45].

3.1. Microbial synthesis of silver nanoparticles (AgNPs)

The use of microorganisms as environmentally sustainable precursor for the production of nanoparticles such as silver or gold has just achieved a lot of interest. Nowadays, bacteria and fungi play a significant function in the remediation of noxious metals through the reduction of metal ions. *Pseudomonas stutzeri* is mainly resistant to silver, and this property is credited to the intracellular buildup of silver crystals of just about 200 nm in diameter and of a definite composition and shape [7,46–48]. The function of bacteria is the superior method for fabrication of ecological and profitable AgNPs. The rapid and high fabrication of silver nanoparticles was synthesized by the optimized culture of *Bacillus sp.* [49].

An interesting study by Safiuddin et al. [47] illustrated the *Bacillus subtilis* has shown that the nanoparticles are in the range of 5–50 nm and the synthesis of extracellular have a potential on the production of mono dispersed particle. The development of this green synthesis using the cell filtrates in combination with microwave irradiation on the synthesis of kinetic AgNPs would be suitable for the production of the mass scale biosynthesis process. From the application point of view, the synthesis of extracellular has a great advantage over the intracellular because the formation of nanoparticle inside the biomass deposit on the desired target area for the different practical purpose unlike the intracellular synthesis.

Research has focused heavily on prokaryotes as a means of synthesizing metallic NPs due to many reasons researchers are giving attention to study bacteria for the synthesis of nanoparticles. This is due to their abundance and adaptation to extreme condition; it’s cost effective for cultivation, fast growing and growth conditions such as temperature, oxygenation and incubation time can be easily controlled [50]. For the synthesis of metallic nanoparticle, fungi have a significant interest over bacteria because it secretes higher amount of protein that amplifies the production of metallic nanoparticle and fungi, scale up and downstream process are very easy, that makes cost-effective and its larger mycelia surface area than bacteria have [50].

Sharma et al. [51] stated that the reduction of aqueous Ag⁺ ions using *Spirulina platensis* cell extracts to synthesis stable AgNPs with no toxicity, cost-effectiveness, rapid reduction, economic viability and environmentally benign [51]. Guangquan et al. [50] were also reported that AgNPs synthesized extracellularly by *Aspergillus terreus* at room temperature. Toxic chemicals as stopping agents can cause the stability of AgNPs at the range of 1–2 nm the antimicrobial activity of AgNPs showed a broad-spectrum which promising the characterization of antimicrobial activity.

3.2. Synthesis silver nanoparticles (AgNPs) using plant extracts

Nowadays, production of NPs focuses on green synthesis from extract of different plant parts. The multipurpose agents of reduction and stabilization of plant extraction for biological synthesis of NPs use to implement green chemistry [52,53]. Extraction of nontoxic plants for synthesis nanoparticle offer natural capping agents. Moreover, in terms of cost for the synthesis of nanoparticle; plant extraction enhances the cost effectiveness over the isolation of microorganism for the feasibility of nanoparticle synthesis [54]. Recently, there is a growing interest in the synthesis of metal nanoparticles by ‘green’ methods. For this purpose, extracts of different plants have been tried with success in reducing agent.

Synthesis of silver nanoparticles using plant extracts diverts the attention of many researchers from the other methods. This is because of plant-mediated nanoparticles are locally available, eco-friendly, cheap and gives the highest yield of nanoparticles and have a broad variety of metabolites that can aid in the reduction of silver ions, and are quicker than microbes in the synthesis [8,38].

Firdhouse and Lalitha [9] review encompassed the various methods of synthesis of silver nanoparticles, its gamut of applications, and concluded spotlights the research work on plant assisted synthesis of AgNPs is an emerging area in the field of nanotechnology. The steady increase in the publications on the aforesaid topic was explored for the benefit of the future researchers. According to Husen and Siddiqi [3] review during the plant-mediated synthesis of metal nanoparticles, all alcohol, aldehyde, phenol and flavonoids present in the plant extract are oxidized into an aldehyde, carboxylicacid, ketone, and flavones respectively, and the metal ions are reduced to metal NPs.

Veerasamy et al. [44] have revealed that the extracting of *G. mangostana* from leaves can produce metal nanostructures through efficient green method that avoids all the hazardous, toxic solvents and wastes from the mangostana. The biosynthesized AgNPs from mangosteen leaf extract provides a good antimicrobial activity. Prabu and Johnson [46] was developed green method for the *Solunmuer basic folium* and *Tylophora ovata*. This method was fast, stable, eco-friendly and have a potential extraction for preparing different metal NPs. The extracted samples are characterized by UV-visible spectroscopy, FESEM, XRD and FTIR measurements and visual examination.

Yadav and Khurana [54] were reported a method for the synthesis of AgNPs using *Cinnamomum tamala* extraction from its leaf. This extraction method has a non-toxic, cost-effective and eco-friendly property. The dispersion of AgNPs in water was used for the synthesis of pyranopyrazoles in quantitative yields as a green catalytic system under mild reaction conditions. Christensen et al. [55] investigated the biological synthesis of AgNPs using *Murraya koenigii* leaf extract was shown rapid synthesis and produce particles of a fairly uniform size and shape. Because the rate of reaction depends on the concentration of broth leaf, as the concentration of broth *Murraya koenigii* leaf increases the rate of reduction that reduce the particle size also increase as well as their agglomeration. Ahmed et al. [56] was studied a simple single-pot green synthesis of stable AgNPs using *Azadirachta indica* leaf extract at room temperature. The synthesis of NPs was found to be efficient in terms of reaction time as well as the stability excluding/reducing agents. This rapid green synthesis confirms eco-friendly, cost effective and an efficient way for the synthesis of AgNPs. Ahmad and Sharma [57] reported achievement of rapid time scales for a synthesis of AgNPs makes a feasible alternative to chemical synthesis methods through biosynthetic pathway, though there still needs a reduction in advance to reduce the particle size. Banerjee et al. [58] were synthesized AgNPs from the leaf extract of Banana, Neem, and those using bioreduction methods successfully. Among the three plants the size of the synthesized of, AgNPs were obtained different in size, and small extraction also yields from banana leaves. De Aragao et al. [59] were revealed on the synthesis of AgNPs using the simple method of extracting the polysaccharide from red algae *Gracilaria birdiae* using reducing and
stabilizing agent. The AgNPs were prepared using three concentrations (0.02, 0.03 and 0.05% v/v) and two pHs (10 and 11) of polysaccharide at stirring for 30 min at 90 °C to synthesis AgNPs. Malikjaruna et al. [60] was reported on the synthesized of AgNPs from the Pepper leaf extract and examined its structure and chemical composition using XRD and EDS with the average sizes of the nanoparticles are found to be 5–60 nm as it indicated from TEM analysis. Naheed Ahmad et al. [61] were presented the synthesis AgNPs from Desmodium plant which have stable and spherically shaped with an average size of ~10 nm.

The most important criteria for the production of synthesis of green silver nanoparticles were based on the selection of solvent, selection of good reducing agent and selection of nontoxic materials. The author gained that Ag nanoparticles presented good antibacterial performance against common pathogens. The nanoparticles when combined with the antibiotics show a synergic effect in suppressing the growth of antibiotics [61].

Rodríguez-León et al. [62] had extracted very promising silver nanoparticles from R. hymenosepalus which used as reducing agent. Nanoparticle having a fast rate of reaction and harmless effect of this chemical makes a better promising method at room temperature. The NMR and UV–vis spectroscopy method observed that Rumex hymenos- palus plant was rich in polyphenols which have antioxidant property.

Porunur selvan et al. [63] conclusion shows that the bioreduction of opaque silver ions by leaf extract of the C. roseus has been studied. Stable AgNPs were synthesized using C. roseus leaf extract by easy control of shape and size. Porunur selvan et al. [63] found that the synthesis of silver nanoparticles from its leaves was a good source for the production of stable nanoparticle. Naturally occurring biomaterials offers an alternative means for production of nanoparticles. The Process scales up nature of nanoparticles also have a great role in the production of zero carbon emission.

Recently, AgNPs synthesis by plants extract divert researchers’ attention and continued to increase its synthesis from various plant extracts such as synthesis of AgNPs from Bunium persicum seeds extract [64], Hamamelis virginiana leaf extract [65], Carpobrotus acinaciformis extract [66], Psychotria nigrirosa leaf extract [67], Rubus ellipticus leaf extract [68], Phyllanthus acidus L. fruit extracts [69], Ag/TiO₂ nanocomposite synthesis using Euphorbia heterophylla leaf extract [70], Ag/zeolite nanocomposite using Euphorbia prolifera leaf extract [71], Ag nanoparticles using Tamarind fruit extract [72], AgNPs using Carpo- brotus acinaciformis extract [66], Ag/RGO nanocomposite by use of Abutilon hirtum leaf extract [73], Euphorbia helioscopia linn as a green source for synthesis of silver [74], Ag and Au nanoparticles using Spinnacia oleracea linn. Leaf extract [75], Ag nanocomposite using Euphorbia heterophylla leaf extract [76]. Use of plant extracts for green of synthesis AgNPs has a quite significant impact on the environmental and economic feasibility. Some researchers reported that silver nanoparticles can synthesis effectively from various type plant extracts with their average size as indicated in Table 1.

4. Application of silver nanoparticles (AgNPs)

Nanotechnology is contributed to sustainable competitiveness and growth in several fields of industrial application [77]. The chemical and physical properties of nanoparticles provide useful functions [78] that are being rapidly exploited in different areas such as in the medicine, biotechnology, material science and energy sectors. On the other hand, biotechnology engages on the molecular, genetic and cellular processes to develop the synthesis of medicines for agricultural purpose [79]. These promising developments in the agricultural sector have their own contribution to overcome the challenges of climate change on food security. Agriculture is the backbone of developing countries, 60% of the population depending on the livelihood [80].

Nanotechnology holds the potential to manage, detect the disease and enhancing the plants to absorb nutrients among other technology. Nanotechnology can improve our understanding of the potential of various crops and enhances the yields or nutritional values. Novel applications of nanoparticles and nonmaterial are growing rapidly on various faces due to their size, distribution, and morphology. Green nanotechnology is expanding its limit in the world of science and technology and same times they call it “the miracle of science” [1].

The great evolution of expanding the nanotechnologies had opened new fundamental innovations for a number of applications. This includes the synthesis physicochemical and optoelectronic properties of nanoscale materials [77,78,81]. Nanostructures widely used for the applications of nanotechnology where the shape and size of the NPs used to determine their characteristic properties. Since the production of the synthesis of NPs is cost-effective and eco-friendly; its demand increases for numerous purposes. As reported by [36,51] the physical and chemical synthesis of nano particles introduced toxic and hazardous materials during the use for antimicrobial activity. Additionally, Biological methods for plant extraction revealed more effective than the chemical and physical. This is because the shape and size of nanoparticle using chemical and physical methods for NPs cannot fit with physicochemical methods.

Currently, new disease-causing organisms such as Avian influenza, HIV/AIDS, the Middle East respiratory syndrome (MERS), Ebola virus, Zika virus [68,82] etc., are exposed on daily basis, this new disease were difficult to overcome their treatment. To overcome these diseases, using AgNPs as the tool is focus many researchers due to their unique physical-chemical and biological properties [82]. Synthesis of nanoparticle using biological methods such as microorganams [43,45], enzymes [46], fungus [47] and plant or plant extracts [48,52] have been proposed as a possible environmental friend which is alternative to chemical and physical methods [48]. Synthesis of silver nanoparticles is extensively used to eliminate the possibility since the extraction of plant for the synthesis of green, silver nanoparticles is cost-effective, simple and eco-friendly method.

Researchers are giving attention on metallic nanoparticles due to its growing microbial resistance against metal ions, antibiotics and development of resistant strains [78]. In the field of nanotechnology AgNPs gained unlimited focus because of its unique property. The chemical stability and catalytic effect of silver nanoparticles have an advantage over the other metallic nanoparticles for antibacterial [2,47], antiviral [44,58], anticancer [75] antifungal and to anti-inflammatory activities [3,4]. Silver has long been recognized as having an inhibitory effect on microbes present in a medical and industrial process [36,37]. In medicine, silver and AgNPs used as ointments to

| Table 1: Plant-mediated synthesis of Silver nanoparticles. |
|-----------------------------------------------|
| S.No. | Plant | Average size (nm) | Reference |
|-------|-------|------------------|-----------|
| 1     | Barley, flax, ryegrass | 0.6–2 | [3] |
| 2     | Lycopersicon esculentum mill, Piper | 40–2, 3–10, 50–55 | [7] |
| 3     | Pedicillium, Centella asiatica l. | 43 and 59 | |
| 4     | Axonopus indica leaf, Triphala | 50 | [44] |
| 5     | Trapa involucrata, Cymbopogon citreron, Solanum verbenaspidium and | 32, 36, 41 and 28 | [46] |
| 6     | C. ternata and Solanum nigrum | 10–50 | [53] |
| 7     | Leaf Extracts | 10 | [54] |
| 8     | Murraya koenigi leaf extract | 10–25 | [55] |
| 9     | Azadirachta indica leave extract | 34 | [56] |
| 10    | Ananas comosus leaf extract | 12 | [57] |
| 11    | M. balbisiana, Azadirachta indica and O. tenuiflorum | 200 | [58] |
| 12    | Seaweed Gracilaria birdiae | 20.3–94.9 | [59] |
| 13    | Pepper leaf broth | 5–60 | [60] |
| 14    | Desmodium plant | 10 | [61] |
| 15    | Rumex hymenosepalus palus root extracts | 2–40 | [61] |
| 16    | Catharanthus roseus leave extract | 35–55 | [63] |
prevent infection against burn and open wounds [1,38]. Additionally, the broad biocidal effect of the biologically synthesized of AgNPs through breaks the cell membrane and disturbs the protein synthesis mechanism in the bacterial system. The disruption of unicellular membrane causes the enzymatic activity. Since biologically synthesized of AgNPs have found highly toxic against different multi-drug resistance of human pathogens. In light of this effect AgNPs disrupts the polymer subunits of the cell membrane [82,83]. The concentration of AgNPs has a tremendous effect on the rupture of the cell wall of the bacteria, as the concentration of the AgNPs increases the permeability of the membrane also high [84].

Conflict interest

The authors declare that there is no conflict.

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