Synthesis and Characterization of Silver Nanoparticles from Ecofriendly Materials: A Review

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Abstract: Recently, silver nanoparticles have been investigated by various researchers due to their unusual optical, electronic and chemical properties. Likewise, depending on their size and shape, many possibilities with respect to technological applications have been advanced. Silver nanoparticle has been discovered as one of the inorganic nano-materials suitable as antimicrobial agents. Hence, synthesis of silver nanoparticles from leaf extracts of numerous plants has been evolving as a cost effective and environmental friendly alternative to chemical and physical methods. The use of plants as major materials for the synthesis of nanoparticles is a green chemistry approach that interconnects nanotechnology and plant biotechnology. The focus of the present review is to examine the various means of synthesis of silver nanoparticles (Ag-NP) using different methods, plant extracts and their characterization as appropriate materials for diverse engineering applications.

Keyword: Renewable materials, ecofriendly, pollution control, adaptation and vegetables

1. INTRODUCTION

Nanotechnology (NT) is the engineering of functional systems at the molecular scale which is the ability to work at the atomic, molecular and supra molecular levels (on a scale of 1 to 100 nm) in order to understand, create and use material structures, devices and systems with fundamentally new properties and functions resulting from their small structure [1]. The term “nanotechnology” can also be defined as the controlled manipulation of materials with at least one dimension less than 100 nm. This technology attempts to integrate chemistry, physics, materials science, and biology to create new material properties that can be exploited to develop facile processes for the production of electronic devices, biomedical products, high performance materials and consumer articles. The commercialization of nanotechnology is expected to boost wide technological development, improve quality of life and societal benefits around the world [2]. The main driver in the field of nanotechnology is not only the small size dimension that can be created with any type of material (metal, ceramic, polymer, glass or composite), but also the unique characteristics of such material, whose size might be controlled to only a few atomic layers in thickness, yet display physical properties which can be very different from the macro scale properties of the same substance. These special and highly fascinating attributes can be accredited to the shape, spacing, confined sizes [3] and also the exceptionally large surface area to volume ratio which has been identified as the key reason for the properties that nanoparticles exhibit as shown in Figure 1 and their dimensions as shown in Table 1 [4-5].

Figure 1: A simple model of the surface area of nanoparticles [5]
Nanoparticles are the simplest form of structures with sizes in the nanometer range. In principle, any collection of atoms bonded together with a structural radius of < 100 nm can be considered a nanoparticle [6]. Currently there are more than 1,317 nanotechnology-based consumer products according to an analysis by Nanotechproject.com [7]. Compared to their counterparts in bulk states, manufactured nanomaterials have the merits of better adjustable electronic properties, better tunable optical properties, and higher reactivity.

Nanostructure materials have existed, and used for specific applications throughout history without knowledge of the small size of the particles involved. An example of the use of nanoparticles can be traced as far back as Roman times, 4th century AD, when the unique properties of colloidal silver and gold were used to produce an array of colours in the Lycurgus cup. The glass of the cup is dichroic; in direct light it turns an opaque greenish-yellow tone resembling jade, and alternatively when light is shown through the glass it turns to a translucent ruby colour [8].

Alongside the advancement into the various disciplines in the recent years, nanoparticles have also been the subject of sporadic research interest for many years, focusing on understanding the origin of these new properties along with the implementation of new instruments and techniques to observe, measure, manipulate and synthesise high quality nanoparticles with desired morphologies that would offer even more manifold perspectives, knowledge and insight into the ever increasing miniaturisation and complexity of technical developments [9].

Silver has over the years provided a very exciting research field due to its interesting optical [10], electronic [11], magnetic [12] and catalytic properties alongside the ability to exhibit the highest electrical and thermal conductivity among all the metals. For this reason, silver nanoparticles are the nanoparticles of choice to use throughout this project [13]. Among all the nano-products, 313 products (23%) are impregnated with nano-sized silver. Silver nanoparticles (AgNP) are used in a wide range of applications, including pharmaceuticals, cosmetics, medical devices, foodware, clothing and water purification, among others uses, due to their antimicrobial properties [14]. The extensive application of the silver nanoparticle (AgNP) results in their inevitable release into the environment. Silver nanoparticles are known as excellent antimicrobial agents, and therefore they could be used as alternative disinfectant agents [15].

Silver NPs are of interest because of the unique properties which can be incorporated into antimicrobial applications, biosensor materials, composite fibers, cryogenic superconducting materials, cosmetic products, and electronic components [16]. There are two major approaches used in synthesizing silver nanoparticles which are top to bottom approach and bottom to top approach, these approaches are made used of in the three methods of synthesizing silver nanoparticles [17]. The three methods are physical, chemical and biological reduction method, Silver nanoparticles (AgNPs) are synthesized by using physical method including laser ablation [18, 19], ball milling [20], evaporation/ condensation [21], sputtering [22], lithography [23], arc discharge, electrodeposition, pulse wire discharge and sonochemical method [24].

Chemical method is based on reduction of silver ions in aqueous or non-aqueous solutions using reducing agents, Silver nitrate, silver acetate, silver citrate and silver chlorate are usually used as silver source, this method employs three main components; (1) metal precursors, (2) reducing agents and (3) stabilizing/capping agents [25]. Chemical and physical methods lead to the presence of some toxic chemical species adsorbed on the surface that may have adverse effects in medical applications. Silver nanoparticles could be produced by using biological agents, which is very helpful for reducing and stabilizing of AgNPs with peculiar properties. Biological agents are having antioxidant or reducing properties and thus easily reduce silver ions into metallic silver. These biological agents are free from toxic chemicals as well as offering natural capping agents for the stabilization of AgNPs. For example, Wang et al. [26] have synthesized silver nanoflowers by using leaf extracts. Jayaprakash et al. [27] have produced AgNPs by using the extract of Piper nigrum (black pepper) as a reducing as well as capping agent in aqueous medium without addition of any other chemicals. Hence, the focus of the present review is to examine the various means of synthesis of silver nanoparticles (Ag-NP) using different methods, plant extracts and their characterization as appropriate materials for diverse engineering applications.

2. SYNTHESIS OF SILVER NANOPARTICLES

There are various methods for synthesis of silver nanoparticles with different shapes like spherical, octahedral, tetrahedral, hexagonal, cubic, wire, coaxial cable, triangular prism, disc, triangular mark, belt, and shell shapes which have effect on the uses of these particles. Syntheses of silver nanoparticles are of two major approaches which are top to bottom and bottom to top approaches. The three methods of synthesis which are physical, chemical and biological reduction method employ these two approaches.
2.1 Physical Approach
Silver nanoparticles (AgNPs) are synthesized by using physical methods like laser ablation, ball milling, evaporation/condensation, sputtering, lithography, arc discharge, electrodeposition, pulse wire discharge and sonochemical methods. The following are brief description of these processes.

Laser ablation
In this method, silver target is ablated by pulsed laser beam in liquid medium [28-32]. The ablation efficiency and the characteristics of produced nano-silver particles depend upon many parameters, including the wavelength of the laser impinging the metallic target, the duration of the laser pulses (in the femto-, pico- and nanosecond regime), the laser fluence, the ablation time duration and the effective liquid medium, with or without the presence of surfactants [33-36]. One important advantage of laser ablation technique compared to other methods for production of metal colloids is the absence of chemical reagents in solutions. Therefore, pure and uncontaminated metal colloids for further applications can be prepared by this technique [37]. For instance, Sportelli et al. [38] have synthesized AgNPs by using laser ablation in the presence of isopropanol without any additional capping agents. The synthesized AgNPs were more stable over several months due to coating of isopropanol molecules with the pulsed, high-energy laser beam. This coating prevents any chemical reaction on colloidal AgNPs and thus achieved larger stability than naked metallic nanoparticles. Bottuiguzza et al., [39] have deposited AgNPs on titanium substrates by using laser ablation in open air. The AgNPs were obtained by ablating silver foil using two different lasers. One was an inert gas jet to prevent oxidation and another one was to direct the ablated material to the substrate. Alva et al., [40] have produced AgNPs in ethanol by laser ablation method with pulsed photoacoustic technique, which is used to determine the production rate per laser pulse and concentration of synthesized AgNPs. Amendola et al., [41] have been produced AgNPs without using any reducing and stabilizing/capping agents in presence of pure acetonitrile and N,N-dimethylformamide by laser ablation of the bulk metal. They had synthesized AgNPs with a carbon shell or included in a carbon matrix.

Evaporation-condensation
In this method, bulk silver is heated at high temperature to produce silver vapours which are condensed as nanoparticles by flowing in inert gas. This method is limited because of large space occupied by the tube furnace, great amount of energy consumption by the furnace while raising the environmental temperature around the source material and a lot of time required achieving thermal stability [42]. Raffi et al., [43] have synthesized AgNPs by using an inert gas condensation method, in which helium was flowing in the process chamber. Nucleation, growth mechanism and the kinetics of nanoparticles formation in vapour phase were also discussed. Harra et al. [44] had generated AgNPs with an evaporation-condensation technique followed by size selection and sintering with a differential mobility analyzer and a tube furnace.

Ball milling method
In this method, size reduction is achieved by dropping a ball from near the top of the container. This container is cylindrically hollow, which rotates about its horizontal axis. The inner surface of the cylindrical container might be lined up with abrasion-resistant material (i.e. rubber). The diameter of the ball mill is approximately equal, which is filled partially in the cylindrical container to grind the bulk silver. The quality of the dispersion is affected by rotational speed, milling time and size of balls. In certain conditions, the particles could be prepared as small as 100 nm [17]. Silver nanoparticles were also prepared by mechanochemical reduction of Ag$_2$O along with graphite. Silver nanoparticles with average crystallite size of 28 nm was achieved after 22 h of milling process [45]. Yadav et al. [46] reviewed the details of the ball milling methods.

Sputtering method
Direct current (DC) magnetron sputtering has long been used to fabricate thin films, nanostructured coatings, and nanoparticles of various materials, including metallic oxide, nitride, and carbide films [47-53]. To produce silver nanoparticles by this process, silver target was bombarded by inert gas ions and silver particles emerged. Chandra et al. [54] have used high pressure sputtering method to fabricate silver nanoparticles (3-60 nm).

Recently, Liu et al. [55] reported on growth of metal nanoparticles, for example, Au and Ag, using DC sputtering systems. The metal targets were sputtered onto ionic liquids to form self-assembly of metal nanoparticles on carbon supports in the liquid. Thus, DC magnetron sputtering could be a potential technique for synthesizing metal nanoparticles. The technique also reduces the complexity of synthesis processes and facilitates control over size, shape, and aggregation of the nanoparticles [56]. However, little research to date has focused on using this technique to synthesize Ag nanoparticles.

Electric discharge method
In this method, pulse voltage is applied between an electrode and a workpiece that are kept close to each other. Dielectric breakdown takes place at a certain distance between the work piece and electrode which causes high heating of the workpiece to melt away small amount. The excess workpiece material is removed with the help of steady flow of the dielectric fluid and also cooling in the machining. If current flows through a workpiece, even a hard metal can be machined [57].

Sonochemical method
Sonochemical effects are the phenomenon of acoustic cavitation in liquids. Cavitation is the formation, growth and collapsing of bubbles in a liquid. Cavitation collapse gives up an intense heating. Vinoth et al. [58] have reported sonochemical method for AgNPs containing reduced graphene oxide.

Physical methods have some advantages such as less time consuming for preparation, and no hazardous chemicals. However, it requires some special devices, high temperature and pressure, longer time for thermal stability, light energy which requiring
high energy for production of AgNPs [59, 60]. Hence, alternative methods are being sought for cost effective synthesis with large scale production of the nanoparticles.

2.2 Chemical Approach

Chemical reduction is the most common used method for synthesis of silver nanoparticles due to its convenience and simple equipment. Control over the growth of metal nanoparticles is required to obtain nanoparticles of small size with a spherical shape and narrow distribution in diameter. It is well known that silver nanoparticles can be produced by chemical reaction at low cost with high yield.

Chemical synthesis process of AgNPs in solution usually employs the following three main components which are: metal precursors, reducing agents and stabilizing/capping agents. The formation of colloidal solutions from the reduction of silver salts involves two stages which are nucleation and subsequent growth. It has been revealed that size and shape of synthesized AgNPs are strongly dependent on these two stages. Besides, for the synthesis of monodisperse AgNPs with uniform size distribution, all nuclei are required to form at the same time. In this case, all the nuclei are likely to have the same or similar size, and then they will have the same subsequent growth. The initial nucleation and the subsequent growth of initial nuclei can be controlled by adjusting the reaction parameters such as reaction temperature, pH, precursors, reduction agents (sodium borohydride, (NaBH₄), ethylene glycol and glucose) and stabilizing agents (polyvinyl alcohol (PVA), polyvinyl pyrrolidone (PVP) and sodium oleate) [61-63].

This method is based on reduction of silver ions in aqueous or non-aqueous solutions using reducing agents. Depending on the conditions, silver ions may favour either the process of nucleation or aggregation to form nanoparticles. Silver nitrate, silver acetate, silver citrate and silver chloride are usually used as silver source. Numerous researchers have synthesized silver nanoparticles using chemical reduction approach, for example, Zaheer et al. [64] have prepared AgNPs by reduction of AgNO₃ solution with aniline in presence of CTAB. They suggested experimentally that concentration of aniline does not have appreciable effect on the shape, size and the size distribution of AgNPs The most frequently used reducing agents among various ones are sodium borohydride, citrate, ascorbate and compounds containing hydroxyl or carbonyl groups like alcohol, aldehydes, carbohydrates and their derivatives [65]. During preparation of nanoparticles, it is paramount to use protective or stabilizing or capping agent which will stabilize dispersed AgNPs in order to prevent agglomeration. Hence, polymeric compounds like polyvinyl pyrrolidone (PVP), polyethylene glycol (PEG), poly (methyl methacrylate) (PMMA), poly(N-isopropylacrylamide) (PNIPA) and poly(methacrylic acid) (PMAA) were used as a capping or stabilizing agents for synthesis of AgNPs.

Khatoon et al. [66] synthesized colloidal AgNPs by using NaBH₄ as reducing agent and trisodium citrate as a stabilizing agent. Different stabilizing agents like gelatin, polyvinyl alcohol (PVA) and polyvinyl pyrrolidone (PVP) were used by Chahar et al. [67] to synthesize colloidal AgNPs. Ye et al., [68] had synthesized AgNPs by using gelatin as a reducing agent and stabilizing agent. The obtained AgNPs were mixed with chitosan (CS), cross linked tannic acid and then freeze-dried to obtain a new composite gelatin/CS/Ag, which has a dense pore structure with a pore size of about 100-250 μm. Gelatin/CS/Ag composite could have antibacterial and wound healing properties and found to be good biocompatible material [68].

Nersissyan et al., [69] had prepared nanosized uniform silver powders and colloidal dispersions from AgNO₃ by a chemical reduction method in the presence of sodium dodecyl sulfate as a surfactant. Wang et al. [70] have discussed to produce AgNPs from silver nitrate and glucose as a reducing agent in presence of polyvinyl pyrrolidone (PVP) solution, whereas NaOH was used to enhance the reaction rate.

Radjiuk et al., [71] prepared AgNPs by reduction of silver nitrate in an excess of aqueous sodium borohydride which be used as a reducing agent. The nanoparticles with a diameter of 20 nm are obtained. Luo et al., [72] reported AgNPs prepared under mild conditions by exploiting polyethylene glycol (PEG), and the dramatic effect of PEG to the formation of AgNPs.

The main advantage of chemical reduction method is that large quantity of nanoparticles can be synthesized within a short period of time. However, the limitations involve the usage of toxic chemicals, costlier chemicals and production of toxic by-products. Hence, there is a need to develop eco-friendly and cost effective route for synthesis of AgNPs. In this regard, green synthesis of AgNPs has being gaining significant importance.

2.3 Biological Approach

The biological synthesis or green synthesis of silver nanoparticles using various leaf revealed a rapid and fairly uniform size particles and shape in an environmental friendly mode. Bioinspired synthesis of nanoparticles provides advancement over chemical and physical methods [73]. Biosynthesis of nanoparticles has been proposed as a cost effective and environmental friendly alternative to chemical and physical methods. Plant mediated synthesis of nanoparticles is a green chemistry approach that interconnects nanotechnology and plant biotechnology [74].

Silver nanoparticles could be produced by using biological agents, which are very helpful for reducing and stabilizing of AgNPs with peculiar properties. Biological agents are having antioxidant or reducing properties and thus, easily reduce silver ions into metallic silver. These biological agents are free from toxic chemicals as well as offering natural capping agents for the stabilization of AgNPs. Various parts of plant like seed, stem, leaf and flower are extensively used for production of AgNPs.
[27], as polysaccharides, biological microorganism such as bacteria and fungus are also used in biosynthetic method which have also emerged as a simple and viable alternative to more complex chemical synthetic procedures to obtain AgNPs. Bacteria are known to produce inorganic materials either intra- or extracellularly. This makes them potential biofactories for the synthesis of nanoparticles like gold and silver. Particularly, silver is well known for its biotical properties [75]. Wang et al. [76] have synthesized silver nanoflowers by using leaf extracts. Jayaprakash et al. [77] have produced AgNPs by using the extract of *Piper nigrum* (black pepper) as a reducing as well as capping agent in aqueous medium without addition of any other chemicals. Rolim et al. [78] have biogenically synthesized AgNPs using a commercial green tea extract (*Camellia sinensis*), which acts as a reducing and stabilizing agents for AgNPs due to presence of polyphenols in green tea. Again Jayaprakash et al. [79] had produced AgNPs using *Tamarindus indica* fruit extract, which acts as a reducing and capping agent. Carbone et al. [80] have prepared AgNPs using white grape pomace aqueous extract (WGPE) as both reducing and capping agent. Laura et al., [81] had biosynthesized silver nanoparticles using *Murraya koenigii* (curry leaf) extract as the reduction and stabilizing agent.

Microorganisms like bacteria, fungi, yeasts and actinomycetes have been used for synthesis of silver nanostructures. Khan et al. [82] have recently produced AgNPs by using bacterial mediated synthesis. This kind of bacterial mediated synthesis could be an alternative approach for chemical (toxic) and physical (high energy required) synthesis methods.

Yin et al. [83] have reported that biosynthesis of AgNPs by human gut microbiota. In this route, human gut microbiota is exposed to aqueous AgNO₃ solution which resulted in the intracellular reduction of silver (I) ions and led to the formation of approximately spherical AgNPs with dimensions of 34 ± 10 nm. Al-Dhabi et al. [84] have produced AgNPs by biosynthetically using the extracellular metabolites of marine derived actinomycetes. The reducing potential of *Streptomyces* sp. Al-Dhabi-89 cell surface extracts was involved for the green synthesis of AgNPs without any external capping substances or agents. They concluded that AgNPs produced from marine *Streptomyces* sp. Al-Dhabi- 89 has shown potential activity against both standard and clinical drug resistant microbial pathogens [84].

Advantages of the biological methods are low cost, ecofriendly, easily scaled up for large scale synthesis and moreover no need of high temperature, pressure, energy and toxic chemicals while the major setbacks of the method was that synthesis of microbe mediated silver nanoparticles (AgNPs) is not industrial feasibility due to their maintenance and highly aseptic conditions.

### Table 2: Plant extracts used for silver synthesis and their potential activity [85]

<table>
<thead>
<tr>
<th>Plant extracts</th>
<th>Potential activity</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternanthera dentate – leaves extract</td>
<td>Antibacterial &amp; antimicrobial</td>
<td>[86]</td>
</tr>
<tr>
<td>Acorus calamus – rhizome</td>
<td>Antioxidant, antimicrobial, anticancerous</td>
<td>[87]</td>
</tr>
<tr>
<td>Abutilon indicum – leaves extract</td>
<td>Antibacterial, antimicrobial</td>
<td>[88]</td>
</tr>
<tr>
<td>Cymbopogon citratus – leaves extract</td>
<td>Antibacterial, antimicrobial, antifungal</td>
<td>[89]</td>
</tr>
<tr>
<td>Thevetia penuviana – latex</td>
<td>Antimicrobial</td>
<td>[90]</td>
</tr>
<tr>
<td>Vitis vinifera – fruit extract</td>
<td>Antimicrobial, antibacterial</td>
<td>[91]</td>
</tr>
<tr>
<td>Musa paradisical – peel extract</td>
<td>Antimicrobial</td>
<td>[92]</td>
</tr>
<tr>
<td>Tribulus terrestris – fruit extract</td>
<td>Antimicrobial</td>
<td>[93]</td>
</tr>
<tr>
<td>Cocculus nucifera – inflorescence extract</td>
<td>Antibacterial</td>
<td>[94]</td>
</tr>
<tr>
<td>Pistacia atlantica – seeds extract</td>
<td>Antibacterial</td>
<td>[95]</td>
</tr>
<tr>
<td>Citrus sinensis – peel extract</td>
<td>Antibacterial</td>
<td>[96]</td>
</tr>
</tbody>
</table>

### Table 3: Green synthesis of silver nanoparticles by different researchers using plant extracts, with the size and shape [97]

<table>
<thead>
<tr>
<th>Plant</th>
<th>Size, nm</th>
<th>Shape</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calotropis procera</td>
<td>150–1000</td>
<td>Spherical</td>
<td>[98]</td>
</tr>
<tr>
<td>Anana comosus</td>
<td>12</td>
<td>Spherical, fcc</td>
<td>[74]</td>
</tr>
<tr>
<td>Murraya koenigii</td>
<td>10–25</td>
<td>Spherical, fcc</td>
<td>[81]</td>
</tr>
<tr>
<td>Emblica officinalis, Terminalia catappa &amp; eucalyptus Hybrid</td>
<td>20–80</td>
<td>Fcc</td>
<td>[1]</td>
</tr>
<tr>
<td>Azadirachta indica</td>
<td>146</td>
<td>Spherical</td>
<td>[99]</td>
</tr>
<tr>
<td>Eucalyptus hybrid</td>
<td>50–150</td>
<td>Spherical</td>
<td>[100]</td>
</tr>
<tr>
<td>Psoralea corylifolia</td>
<td>100–110</td>
<td>Spherical</td>
<td>[101]</td>
</tr>
<tr>
<td>Aloe Vera</td>
<td>50–350</td>
<td>Spherical, triangular</td>
<td>[102]</td>
</tr>
<tr>
<td>Alternanthera dentate</td>
<td>50–100</td>
<td>Spherical</td>
<td>[103]</td>
</tr>
<tr>
<td>Memecylon edule</td>
<td>20–50</td>
<td>Triangular, circular, hexagonal</td>
<td>[104]</td>
</tr>
<tr>
<td>Cinnamomum camphora</td>
<td>48–67</td>
<td>Spherical</td>
<td>[105]</td>
</tr>
<tr>
<td>Dioscorea bulbifera</td>
<td>35–60</td>
<td>triangles, pentagons, hexagons</td>
<td>[106]</td>
</tr>
<tr>
<td>Melia azedarach</td>
<td>78</td>
<td>Spherical</td>
<td>[107]</td>
</tr>
<tr>
<td>Datura metel</td>
<td>16–40</td>
<td>Quasilinear superstructures</td>
<td>[108]</td>
</tr>
<tr>
<td>Nelumbo nucifera</td>
<td>25–80</td>
<td>Spherical, triangular</td>
<td>[109]</td>
</tr>
<tr>
<td>Rosa rugosa</td>
<td>30–60</td>
<td>Spherical</td>
<td>[110]</td>
</tr>
<tr>
<td>Tea extract Leaves</td>
<td>20–90</td>
<td>Spherical</td>
<td>[111]</td>
</tr>
<tr>
<td>Chenopodium album</td>
<td>10–30</td>
<td>quasi-spherical</td>
<td>[112]</td>
</tr>
<tr>
<td>Vitex negundo</td>
<td>5 &amp; 10–30</td>
<td>Spherical &amp; FCC</td>
<td>[113]</td>
</tr>
<tr>
<td>Cinnamomum camphora</td>
<td>3.2–20</td>
<td>cubic, hexagonal crystalline</td>
<td>[74]</td>
</tr>
</tbody>
</table>

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3. CHARACTERIZATION OF SILVER NANOPARTICLES

Characterization of silver nanoparticle is important in order to understand and control nanoparticles synthesis and applications. Different techniques such as transmission and scanning electron microscopy (TEM, SEM), dynamic light scattering (DLS), X-ray photoelectron spectroscopy (XPS), powder X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), and UV–Vis spectroscopy are used to determine various parameters of the synthesized nanoparticles [114-124]. These techniques are used for determination of different parameters such as particle size, shape, crystallinity, fractal dimensions, pore size and surface area. Moreover, orientation, intercalation and dispersion of nanoparticles and nanotubes in nanocomposite materials could be determined by these techniques.

The surface morphology and particle size of AgNPs is observed using transmission electron microscopy, scanning electron microscopy and Atomic force microscopy, (TEM, SEM, AFM). The size distribution of AgNPs can be measured with a Zetasizer Nano Series analyzer. Energy dispersive X-ray spectroscopy (EDS) measurements are used with an emission scanning electron microscope equipped with an EDS instrument for the determination of the purity of synthesized nanoparticle. X-ray photoelectron spectroscopy (XPS), X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), and UV-Vis spectroscopy are also used to characterize AgNPs. Dynamic light scattering is used for determination of particle size distribution. UV-Vis spectroscopy is used to confirm AgNPs formation by showing the Plasmon resonance. Moreover, XRD is used for the determination of crystallinity. Figures 2-8 showed some of the results obtained from these characterizations.

Figure 2: UV-Vis absorption spectra of silver nanoparticles synthesised by both chemical and biological means Gudikandula and Maringanti [125]

Figure 3: Imaging of Ag NPs and evaluation of NP size from SEM measurements Daniele Barocco et al., [126]
Figure 4: XRD spectrum of AgNp synthesized from extract of Ananas comosus [74]

Figure 5. HRTEM micrograph recorded on a drop-coated film with Ananas comosus fruit extract and AgNPs aqueous suspension [74]
Fig. 6: TEM images of the biosynthesized silver nanoparticles using concentrations of leaf broth (curry leaf) [81]

Figure 7: SEM micrograph of silver nanoparticles synthesized with *azadirachta indica* plant extract [17]
4. APPLICATION OF SILVER NANOPARTICLES

Silver nanoparticles have found applications in many field due to its unique properties. Some of its areas of applications are follows;

4.1 Medical Science Applications
Application of Ag NPs in medical can be divided into two types, namely diagnostic and therapeutic uses. Lim et al found that Surface Enhanced Raman Spectroscopy (SERS) based on Ag NPs can be used in cancer detection in non-invasive way [127]. This process of cancer detection will be inevitable part of cancer detection in near future. Now a days silver nanoparticle is widely used in medical science. It is used for wound dressing, scaffolds, eye treatment and dental hygiene [128] bone substitute biomaterials [129]. By Incorporating Silver Nanoparticles at surface antibacterial properties can be increased without affecting biocompatibility [128] and also provides superior cosmetic after wound healing and better efficacy. Silver contained materials are used for surgical meshes. Central venous catheters (CVC) contained silver nanoparticles are less infective in blood stream [130]. According to Sun et al. [131] human serum contains albumin stabilized silver nanoparticle which provides antiviral properties. Recent studies of Ag NPs lead to utilization in some important applications such as diagnostic imaging, therapy, bio-sensing and cancer diagnosis. [132]. Ag NPs are considered to be used as drug delivery vehicles and cancer therapeutic agents. Interferon gamma and tumor necrosis can also be inhibited by Ag nano-particles [133]. Nano silver can be used for destroying unwanted cells due to its plasmonic nature. This operation can be done by absorbing light from target cell and then converting to thermal energy. The plasmonic nature of Nano silver can also be used to destroy unwanted cells. The cells can be conjugated to the target cells and then be used to absorb light and convert it to thermal energy; the thermal energy can lead to thermal ablation of the target cells [134].

Silver nanoparticles (AgNPs) loaded in chitosan/gelatin blend: Ag NPs-containing chitosan/gelatin (CS/G) polymers exhibit strong antibacterial activity against Staphylococcus aureus strains and Escherichia coli strains, limited cytotoxicity, good bond strength with metal substrate and good biodegradability [135]. It is also important to mention that the initial burst release of Ag ions prevent the initial adhesion of bacterial strains while exhibiting relatively low cytotoxicity to healthy cells creating the premises of reduce implant-associated infections. Also, these formulations can be used in wound dressing for preventing or eradicating infection [136]

4.2 Textile Applications
Nano materials are now commercially used in textile industries [137]. Nanoparticles are incorporated into fiber or coated on fiber. Silver nanoparticles are used in T shirt, sporting clothes, underwear, socks etc. [138].

Figure 8: EDX spectra of sliver nanoparticles synthesized with azadirachta indica plant extract [17]
Various textiles were functionalized by silver to induce antimicrobial surfaces. After the functionalization, the Ag NPs-fabrics exhibited antimicrobial properties in the order silk> linen> nylon> PET. The morphology of the silver nanoparticles is substrate-dependent, but also the content of silver differs considerably, the highest amount of silver can be found on silk (12.05 ±0.41 g AgNPs/kg) followed by PET (5.77±0.21gNPs/kg), linen (4.37±0.89gAgNPs/kg) and finally nylon (2.65±0.05g AgNPs/kg) [139].

4.3 Energy applications

AgSiO$_2$ nanospheres were designed to obtain Plasmonic Organic solar cells. The optimization was done considering the periodicity of the array, the Ag core diameter, the active layer thickness, the shell thickness, and the refractive index of the shell materials. Based on the study realized by N’Konou et al. [140] it was found that the optimal periodicity of the AgSiO$_2$ nanospheres (50nm) can improve the optical absorption with 24.7% (compared to the similar structure without AgSiO$_2$ nanospheres).

Wearable supercapacitors with core/shell hierarchical structure based on silver coated textile and nanostructured active materials were obtained using metal hydroxide (e.g. Ni(OH)$_2$, NI-Co layered double hydroxide(LDH)), hydrates (e.g. NiMoO$_4$ hydrate), and sulphides (e.g. Ni(Fe)Co$_2$S$_4$) with three typical nanostructures of a 1D nanotube array, a 1D nano rod array, 2D nanosheet network. As a general conclusion of the work published by Li et al. [141], both the nature of the active materials but also the morphology is critical factors affecting the performances of the wearable super capacitor.

4.4 Food Industry Applications

Silver nanoparticles are widely used in food industry reported by Cushen [142] mainly due to antibacterial actions and free of preservative. Small concentration of Ag NPs is harmless for human cell but deadly for majority of viruses and bacteria. For this reason it is extensively used in decontamination of food and water in day to day lifecycle and infection resistor in medicine. Nanoparticles are added into food packages. Sunriver industrial Nano silver fresh food bag is one of commercially available bag in which silver nanoparticles are added [143]. Ag NPs are widely used in consumer product namely soaps, food, plastics, pastes and textiles due to their anti-fungicidal and anti-bacterial activities.

4.5 Anti-Parasitic and Anti-Fouling Action

The Silver nanoparticles have been found to be effective larvicidal agents against dengue vector Aedes aegypt and Culex quinquefasciatus, filariasis vector C. quinquefasciatus and malarial vector A. subpictus, Aedes aegypt, A. subpictu and other parasites.

The Silver nanoparticles synthesized from Rhizopus oryzae fungal species have been used for treating contaminated water and adsorption of pesticides and that from Lactobacillus fermentum cells have been used as anti-bio fouling agent. The Silver nanoparticles are being used to treat many environmental concerns like; air disinfection, water disinfection, ground water and biological water disinfection and surface disinfection [144].

5. CONCLUSION

In this paper, review on the existing methods, characterization and applications of silver nanoparticles has been carried out. Biological method of synthesis for silver nanoparticle was noticed to be the best compared to physical and chemical methods. The work reveals a future prospect for the use of silver nanoparticle in particular from the biological method of production. The various areas of application of silver nanoparticle also contribute to the interest in the advancement of its manufacturing process. Hence, more attention needed to be given to synthesis of the nanoparticle from this approach in other to overcome the present limitations. This became necessary due to environmental benefits unlike chemical approach that produce toxic material that is hazardous to the environment.

REFERENCE


aviciene one of silver nanoparticles.


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