Chapter

Biological and Physical Applications of Silver Nanoparticles with Emerging Trends of Green Synthesis

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Abstract

Among the emerging nanotechnology, nanoparticles get much attention due to their unique physicochemical, optical, electrical, and thermal activities. Nowadays, extensive research on silver nanoparticles is going on due to their wide applicability in different fields. Silver nanoparticles possess excellent anticancer as well as antimicrobial efficacy (hence found major and wide applications as antimicrobial, wound healing, antidiarrheal, and antifungal agents). A huge and advanced perspective of silver nanoparticles is found in environmental hygiene and sterilization due to their magnificent disinfectant properties. The other major applications of silver nanoparticles include diagnostic (as biological tags in biosensors, assays, and quantitative detection), conductive (in conductive inks, pastes, and fillers), optical (metal-enhanced fluorescence and surface-enhanced Raman scattering), and household (pesticides and wastewater treatment) applications. The present review consists of an exhaustive detail about the biological and physical applications of silver nanoparticles along with the analysis of historical evolution, the present scenario, and possible future outcomes.

Keywords: silver nanoparticles, anticancer, antimicrobial, environmental hygiene, biosensors

1. Introduction

In this modern era, pharmaceutical research associated with nano-sized products is rapidly growing. Nanoscience/technology has changed the way of diagnosing, treating, and curing the diseases which proves to be a great change in human life. Nano-sized formulations/products include nano-emulsion, ethosomes, liposomes, nanoparticles, etc. Nanoparticles ranging from 1 to 100 nm are in trend nowadays due to its size-depending optical, thermal, electrical, and biological properties [1]. Nano-sized metallic particles are unique because they can considerably change their chemical, physical, and biological properties because of their surface-to-volume ratio. Silver nanoparticles have unique physical and chemical properties among other metallic nanoparticles; besides this, its wide applications in different fields make them the most catchy and different from all other nano-formulations. Silver nanoparticles are well recognized for their diagnostic (as biological tags in

biosensors, assays, and quantitative detection), conductive (in conductive inks, pastes, and fillers), optical (metal-enhanced fluorescence and surface-enhanced Raman scattering), and household (pesticides and wastewater treatment) applications. Silver nanoparticles gained their immense attraction due to its magnificent role in cancer treatment. The biological activity of silver nanoparticles depends upon various factors like surface morphology, surface chemistry, size, size distribution, cell type, cell agglomeration, and reducing agent used for the synthesis of nanoparticles. Silver nanoparticles were firstly recorded by M.C. Lea; by citrate reduction method, he produced stabilized silver colloids. Many methods are there for the synthesis of silver nanoparticle which include a physical method, chemical method, biological method, etc. Physical and chemical methods are somewhat hazardous and costly, whereas biological methods are safe and are simpler to apply for the synthesis of silver nanoparticles. After synthesis and before applying it for any purpose, silver nanoparticles must pass all the characteristic parameters like size, shape, size distribution, surface area, solubility, aggregation, toxicity, and biocompatibility. Many techniques have been used to evaluate all these parameters like UV-Vis spectroscopy, differential screening calorimetry (DSC), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), dynamic light scattering (DLS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), and atomic force microscopy (AFM) [2–6].

Advantages of silver nanoparticles [7]:

- There is a possibility of high-scale production of silver nanoparticles.
- Silver nanoparticles possess long-term stability.
- Controlled drug delivery of silver nanoparticles can be achieved.
- Silver nanoparticles can be freeze-dried and lyophilized to get powder formulation.

Disadvantages of silver nanoparticles [7]:

- Less drug loading capacity.
- Dispersion of silver nanoparticles includes some amount of water.
- The less capacity to load lipophobic drugs.

2. Methods of preparation

2.1 Physical methods

Physical methods use physical energies to produce the silver nanoparticles with narrow size distribution. Physical methods produce a large quantity of silver nanoparticles in a single process. These methods are also able to give silver nanoparticle powder (**Figure 1**) [8].

2.1.1 Evaporation-condensation method

In this method, the metallic (silver-organic) source is kept in the boat with the heat center in a tube furnace. Center heat is enough to evaporate the non-silver

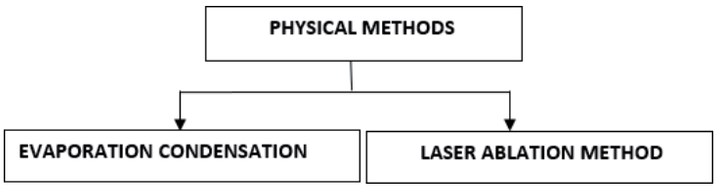

Figure 1.
Physical methods for the preparation of silver nanoparticles.

particles which get eliminated with the carrier gas leaving behind the silver nanoparticles. The more the temperature of the furnace, the more the concentration of silver nanoparticles formed. But this method takes a quite large time to reach stabilized temperature [9].

2.1.2 Laser ablation method

In this method, metallic/silver plate is dispersed in a liquid medium and illuminated with a laser beam. The metal plate absorbs the laser beam and forms a hot plasma which contains silver particles in maximum concentration. The liquid medium lowers down the temperature and cools the vicinity which initiates the formation of silver nanoparticles. The nature of the silver nanoparticles formed and the ablation efficiency depends upon many factors such as the wavelength of the laser impinging the metallic target, the duration of the laser pulses (in the femto-, pico-, and nanosecond regime), the laser fluency, the ablation time duration, and the effective liquid medium, with or without the presence of surfactants [1].

The major advantage of both the methods is that it does not include any chemical/reducing and stabilizing agent; therefore, the silver nanoparticles produced by these methods are contamination free and do not need to be purified for further application. However, the major disadvantage is that they consume high energy and costly. Due to these drawbacks, some methods were adopted which are also based on this physical approach but overcome these limitations. These adopted methods are like using ceramic heater which uses less energy and produces continuous heat without any fluctuation and where there is a steep temperature gradient in the vicinity. The second method adopted is thermal decomposition method which produces the silver nanoparticles in solid form. This method works on the principal of complexation between silver and oleate ions and gives silver nanoparticles with 10 nm size. The arch dispersion method was also adopted to overcome the abovementioned limitations and involves the formation of silver nanoparticles in deionized water and does not include the incorporation of any surfactant; it yields silver nanoparticles with less than 10 nm size and hence proves to be a very efficient method [1, 9].

2.2 Chemical methods

These methods are most employed in synthesizing the silver nanoparticles. These methods are based on the reduction of silver ions to the silver atoms which get agglomerated to form the oligomeric clusters which lead to form silver nanoparticles. Various precursors are used in these methods like silver nitrate ($AgNO_3$), silver acetate, and silver chlorate. In these precursors reducing agents like ascorbate, borohydride, and compounds with the hydroxyl and carboxyl group like alcohol, aldehyde, and carbohydrates are incorporated which reduce the silver ion in the precursor and form the silver atom followed by formation of silver nanoparticles. The silver nanoparticles formed are greatly influenced by the nature and properties of reducing agents. The reducing agents are categorized into strong

and mild reductants. The strong reductants like borohydrides give large-sized monodispersed nanoparticles, whereas ascorbates and citrates produce small-sized nanoparticles with wide dispersion. Besides this, the morphology (size and shape) of nanoparticles depends upon the type of dispersion medium. The dispersion mediums are a solvent system which acts as the protective or stabilizing agent and is absorbed on the particle surface to prevent agglomeration. Various solvent systems used are mostly polymers like polyvinylpyrrolidone (PVP), polymethylmethacrylate (PMMA), polymethyl acrylic acid (PMAA), and polyethylene glycol (PEG). Polymers are the best candidate as stabilizing agents [10, 11].

2.3 Biological methods

The chemical methods involve a large number of chemical agents like stabilizers (PVP, PMMA, PMAA, and PEG), reducing agents (borohydrides, citrates, and ascorbates) which turns the final product (silver nanoparticles) contaminated. To overcome these limitations, the natural reducing agents are being used nowadays, and this method refers to a biological or green method which is eco-friendly, gives contamination-free product, and consumes less energy. The natural reducing agents like biological microorganisms such as bacteria, fungus, and plant extract are used. The basic principle of this method is that all the natural reducing agents like flavonoids, oils, terpenoids, carbohydrates, enzymes, etc. give an electron to reduce silver ions to silver atoms. This method proves to be a simpler viable alternative to the complex chemical methods to obtain silver nanoparticles. Bacteria are known to be very effective natural reducing agents which give organic and inorganic material, intracellularly and extracellularly. There is a wide range of biological reducing agents available which hence gives a wide choice of precursors for this method (**Figure 2**) [12, 13].

2.4 Other methods

2.4.1 Photochemical method

Photochemical method uses light especially UV light to transform solution of colloidal silver nanoparticles to stable formulation with different sizes and shapes (**Figure 3**). In this method, the precursor source is a silver colloidal solution

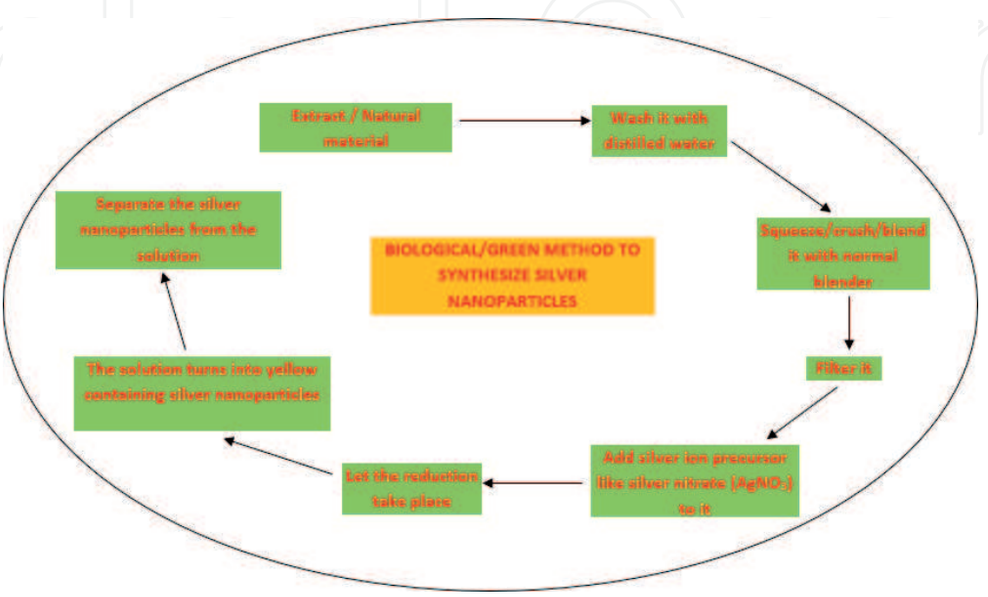

Figure 2.
Overview of the synthesis of silver nanoparticles by the green method.

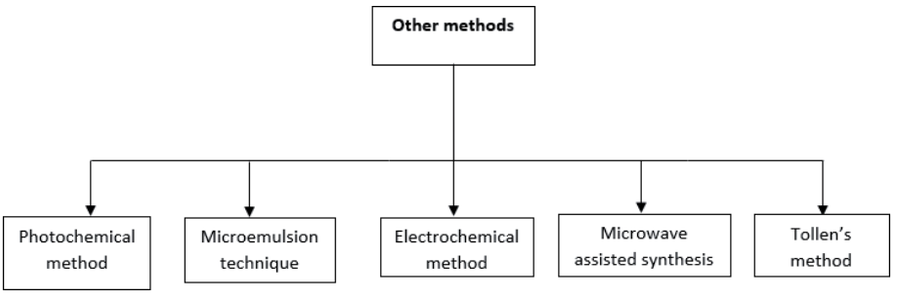

Figure 3.
Other conventional approaches for the synthesis of silver nanoparticles.

(silver nitrate, silver perchlorate, etc.) which gets photochemically reduced to form the silver nanoparticles in the presence of polymer stabilizers such as PVP, PMMA, and PMAA. The growth of the nanoparticles formed by this method can be controlled by choosing the concentration of stabilizers and type of light source [8, 9].

2.4.2 Electrochemical method

In this method, the silver nanoparticles are formed in a special electrochemical cell in which the silver acts as an anode and the platinum acts as a cathode. The external electrical field is applied to the silver anode which in turn forms the silver clusters followed by the formulation of silver nanoparticles that get deposits on the platinum cathode. This process is conducted at the room temperature, and current density can control the size of silver nanoparticles [9].

2.4.3 Microemulsion technique

The silver nanoparticles of controllable and uniform size can be synthesized by this technique. The metal precursor and the reducing agent are firstly separated in the two immiscible liquids; the intensity at the interphase and interphase transporters which are mediated by the quaternary ammonium sulfate affects the rate of interaction between metal precursors and reducing agents. The silver nanoparticle clusters when formed at the interphase get stabilized by the stabilizers at the interphase and then transported to the organic solvents by interphase transporter. The major disadvantages of this method are that the organic solvents which are used are deleterious in nature and that the final product is contaminated in nature and must be separated from the surfactants and organic solvents for further applications which are quite difficult [1].

2.4.4 Microwave-assisted synthesis

In this method, unlike conventional oil bath heating method, microwave heating is used to synthesize the silver nanoparticles. It is a promising method nowadays because microwave heating has a shorter reaction time, reduced energy consumption, and better yield of product which prevent the agglomeration of particles formed. This synthesis involves the carboxymethyl cellulose sodium as a stabilizer. The nanoparticles formed by this have the stability of 2 months without any visual change. Microwave-heated starch is used as a stabilizer which also serves as a template. Polyols like polyethylene glycol and N-vinylpyrrolidine are used as reducing agents as well as stabilizers in which inorganic salt is reduced to form nanoparticles [1].

2.4.5 Tollens method

In this method, the $Ag(NH_3)_2^+$ (Tollens reagent) is reduced by saccharides in the presence of ammonia which yields silver nanoparticle films of size 20–50 nm and silver nanoparticles of different sizes. The pH is usually between the 11.5 and 13.0. pH also influences the particle size as at low pH the size of nanoparticles is comparatively small. The polydispersity of the silver nanoparticles can be achieved by lowering the pH [1].

3. Characterization

3.1 UV-Vis spectroscopy

The absorbance of plasmon is responsible for giving a specific color to the nanoparticles. The electromagnetic radiations and the conduction electron are absorbed by the incident light oscillations and hence produce a specific color. The plasmon sample is diluted with the distilled water generally, and silver nanoparticles show peak near about 400 nm. The lambda max of the plasmon resonance solution is responsible for indicating the size of the formulation (**Figure 4**) [2, 3].

3.2 Fourier transform infrared spectroscopy

In this method, the functional group of the silver nanoparticles is detected. The transmittance goal of silver nanoparticles can be found at 490 nm, and the signaling of OH near 3499 cm [2, 3].

3.3 X-ray diffraction

The XRD depicts the crystalline structure of nanoparticles. When X-rays reflect on the sample (crystal structure), it reflect different diffracted patterns. From these patterns, various physicochemical properties of the sample can be predicted. The X-ray diffraction pattern is matched with the standard/reference pattern of the sample, and from this impurities can be detected easily. There is interplanar spacing in the diffraction pattern which is also called d values; these d values are matched with standard silver values. The average crystalline size of nanoparticles can be calculated using Debye-Scherrer formula:

$$D = \frac{k}{b \cos q} \quad (1)$$

where D is the average crystalline size of the nanoparticles, k is the geometric factor (0.9), λ is the wavelength of X-ray radiation source, and b is the angular full-width at half maximum (FWHM) of the XRD peak at the diffraction angle. From this formula the average size of the silver nanoparticles can be calculated [3, 14].

3.4 Atomic force microscopy

Atomic force microscopy characterizes not only the size shape and sorption but also the dispersion and aggregation of the nanoparticles. AFM helps in the measurement of real-time interactions of nanoparticles with the lipid biological layers, which cannot be achieved by current electron microscopy techniques. No conductive surface or oxide-free surface is required for the measurement in the atomic

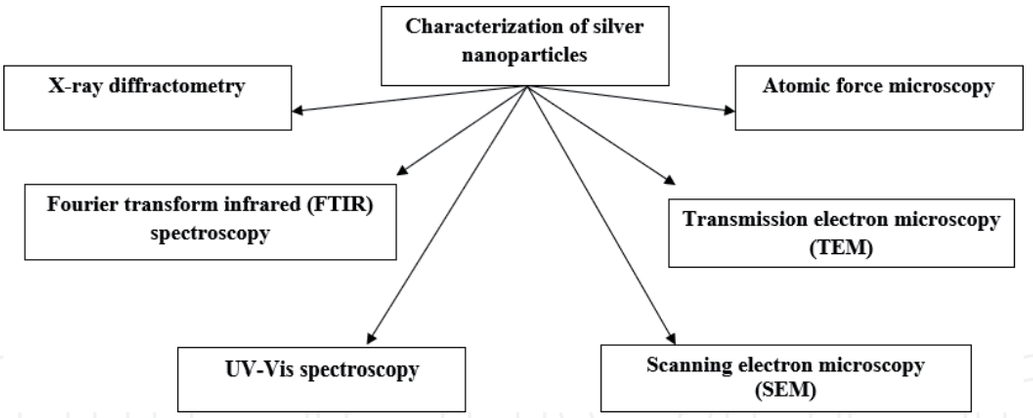

Figure 4.
Various techniques used in the characterization of silver nanoparticles.

force microscopy. In addition to this, the major advantage of AFM is that it does not cause any destruction to the native surface and can measure sub-nanometer scale in aqueous fluids. However, the major drawback is the overestimation of the lateral dimensions of the sample due to the size of the cantilever. The operating mode (no contact or contact) is a very crucial factor in sample analysis [2].

3.5 Scanning electron microscopy

It is a high-resolution technique/microscopy used to detect whole morphology and surface characteristics of the nanoparticles. It is based on the reflection of very high energetic electrons to the probe object. It is a very efficient method to resolve different particle sizes, size distributions, and nanomaterial shapes. The surface morphology of the micro- and nanoscale particles can be easily detected by using SEM. By the histogram obtained particles can be counted either manually or using any software. More specifically for the determination of surface morphology and chemical composition of silver nanoparticles, SEM can be combined with the energy-dispersive X-ray spectroscopy (EDX). The major advantage of this technique is that it can identify the morphology of nanoparticles having size below 10 nm; however, the drawback of this technique is that it is not helpful in determination of the internal structure of the nanoparticles [3].

3.6 Transmission electron microscopy

TEM is a quantitative method for determination of particles, particle size, size distribution, and morphology. In this technique, the resolution is based upon the ratio of distance between the objective lens and specimen and distance between objective lens and image plane. The major advantages of this technique over the SEM are that it has better efficiency of spatial resolution and other analytical measurements can also be done by this technique. However, the major disadvantage of TEM is sample preparation which is a highly crucial step for better imaging and is highly time-consuming; in addition to this, another disadvantage is high-vacuum and very fine and thin sections of sample are required which are quite difficult to maintain and prepare, respectively [2].

4. Applications of silver nanoparticles

Applications of silver nanoparticles can be classified in two major classes, that is, therapeutic and physical applications (**Figure 5**).

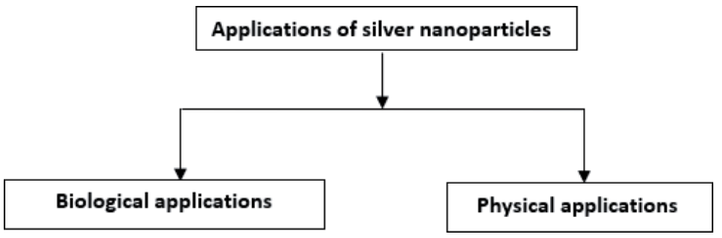

Figure 5.
Applications of silver nanoparticles.

4.1 Biological applications

Silver nanoparticles have various biological applications (**Figure 6**) majorly antimicrobial, anticancer, antioxidant, anti-inflammatory, wound healing, antimalarial, etc. Inbathamiz et al. synthesized silver nanoparticles using aqueous extract of *Morinda pubescens* by reducing silver nitrate and evaluate them in vitro for their antioxidant (using DPPH, ferric thiocyanate, thiobarbituric acid, superoxide anion radical scavenging, H_2O_2, metal chelating, and phosphomolybdenum-like assay) and anticancer potential (by MTT assay on human epithelium cells of liver cancer (HepG2)). They found that silver nanoparticles have high antioxidant capacity as well as cytotoxic activity against HepG2 cell lines [15]. Logeswari et al. synthesized silver nanoparticles using extracts of *Ocimum tenuiflorum*, *Syzygium cumini*, *Solanum trilobatum*, *Centella asiatica*, and *Citrus sinensis* from silver nitrate solution. Prepared silver nanoparticles were evaluated for antimicrobial activity against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumonia*, and *Pseudomonas aeruginosa* using disk diffusion method. Results revealed that silver nanoparticles synthesized from *Solanum trilobatum* and *Ocimum tenuiflorum* possess the highest antimicrobial activity against *Staphylococcus aureus* (30 mm) and *Escherichia coli* (30 mm), respectively [16].

Most of the urinary tract infections are caused by *Proteus mirabilis*, *Escherichia coli*, *Serratia marcescens*, and *Pseudomonas aeruginosa*. These bacterial pathogens

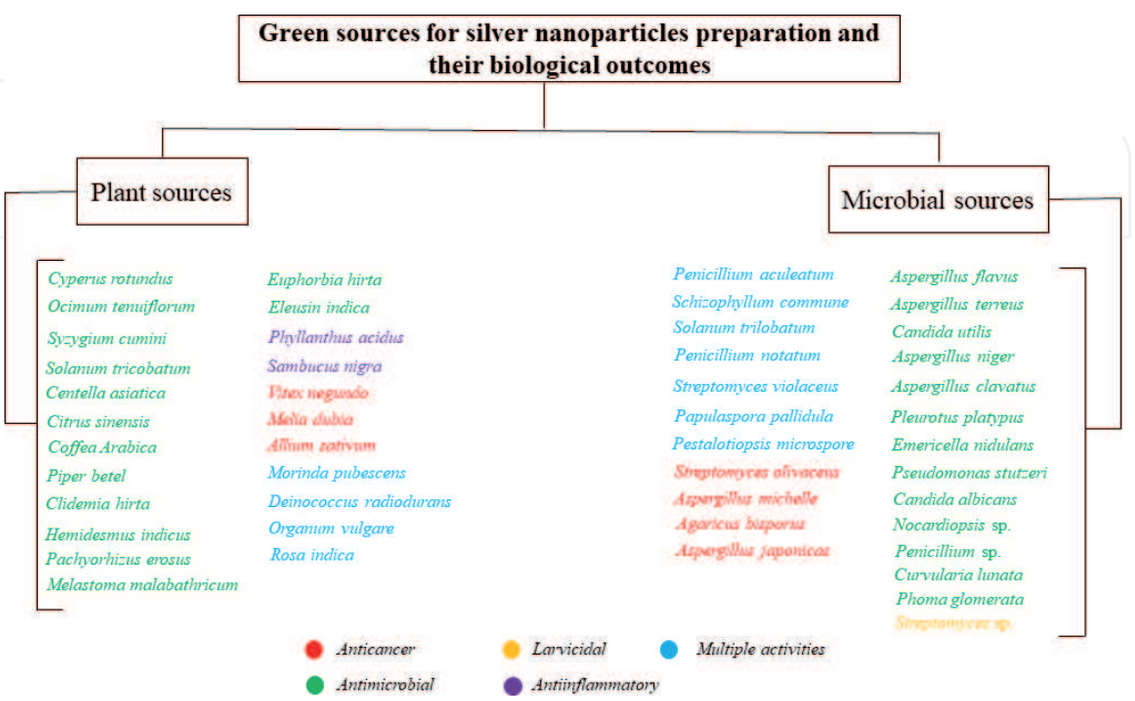

Figure 6.
Natural sources used for preparation of silver nanoparticles and their biological potential.

possess quorum sensing (QS) machinery to coordinate their cells and regulate several virulence factors as well as in biofilm formation. Srinivasan et al. prepared silver nanoparticles using *Piper betle* leaf extract from silver nitrate aqueous solution and evaluate them for anti-QS and antibiofilm potential. Results revealed that prepared silver nanoparticles were able to inhibit QS-mediated virulence factors such as protease, prodigiosin, biofilm formation, and exopolysaccharides as well as hydrophobicity productions in uropathogens. In vivo *Caenorhabditis elegans* assays also revealed their nontoxic and anti-adherence efficacy. Therefore, it was concluded that silver nanoparticles can be an effective alternative toward the conventional antibiotics in controlling QS and biofilm-related uropathogenic infections [17].

Exopolysaccharide of the *Streptomyces violaceus* composed of total carbohydrate (61.4%), ash content (16.1%), and moisture content (1.8%) was efficiently used by Sivasankar et al. for synthesis of silver nanoparticles. Prepared silver nanoparticles were evaluated for antibacterial (against *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, and *Bacillus subtilis*) and antioxidant (using 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, total antioxidant activity, H_2O_2 scavenging activity, nitric oxide scavenging activity, and ferric reducing power) activities. Results revealed that silver nanoparticles have promising antimicrobial and antioxidant activity [18]. Salama et al. synthesized a series of nanocomposites based on chitosan biguanide-grafted poly(3-hydroxybutyrate) copolymer (ChG-g-PHB) and silver nanoparticles via in situ reduction of silver nitrate in copolymer matrix and evaluated them for antimicrobial activity against *Streptococcus pneumonia*, *Escherichia coli*, *Salmonella typhi*, and *Aspergillus fumigatus*. Results revealed that sample loaded with 3.0% silver nanoparticles has best antimicrobial activity (MIC 0.98–1.95 μg/ml) [19]. Dried roasted *Coffea Arabica* seed extract was used by Dhand et al. for the synthesis of silver nanoparticles from silver nitrate and evaluated for antibacterial potential against *Escherichia coli* and *Staphylococcus aureus*; results confirmed the decrease in bacterial growth with well-defined inhibition zones [20].

Boonkaew et al. developed a burn wound dressing that contains silver nanoparticles to treat infection in a 2-acrylamide-2-methylpropane sulfonic acid sodium salt ($AMPSNa^+$) hydrogel and revealed that hydrogels were nontoxic to normal human dermal fibroblast cells as well as had good action against *Pseudomonas aeruginosa* and methicillin-resistant *Staphylococcus aureus*. They also revealed that 5 mm silver hydrogel was efficient in preventing bacterial colonization of wounds, and results were comparable to the commercially available silver dressings (Acticoat™, PolyMem Silver®) [21]. David et al. did an eco-friendly extracellular biosynthesis of silver nanoparticles using european black elderberry (*Sambucus nigra*) fruit extracts and evaluated them for their in vitro anti-inflammatory activity on HaCaT cells exposed to UVB radiation, in vivo on acute inflammation model, and in humans on psoriasis lesions. Results revealed that silver nanoparticles decrease cytokine production induced by UVB radiation and pre-administration of silver nanoparticles reduces edema and cytokine level in paw tissues after inflammation induction. They also demonstrate the possible use of silver nanoparticles in psoriasis lesions [22]. Silver nanoparticles prepared by chemical reduction from aqueous solution ranged from 10 to 20 nm, and on antibacterial evaluation using Kirby-Bauer method, it was revealed that they have bactericidal activity against *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* [23]. Kathiravan et al. synthesized silver nanoparticles using plant extract of *Melia dubia* and evaluated them against human breast cancer (KB) cell line. Results revealed that prepared silver nanoparticles had remarkable cytotoxicity against KB cell line with high therapeutic index [24]. Latha et al. synthesized silver nanoparticles using leaf extract of *Hemidesmus indicus* and evaluated them for antibacterial activity against the isolated bacteria *Shigella sonnei*

using agar bioassay, well diffusion assay, and confocal laser scanning microscopy (CLSM) assay. Results revealed that silver nanoparticles have higher inhibitory activity (34 mm) at 40 μg/ml [25].

Ramar et al. synthesized silver nanoparticles using ethanolic extract of rose (*Rosa indica*) petals and evaluated them for their antibacterial activity against selective human pathogenic microbes and anticancer activity against human colon adenocarcinoma cancer cell line HCT-15. Results revealed that silver nanoparticles were effective against *Escherichia coli*, *Klebsiella pneumonia*, *Streptococcus mutans*, and *Enterococcus faecalis*. The MTT assay, nuclear morphology analysis, mRNA expression of Bcl-2, and Bax and protein expression of caspase 3 as well as caspase 9 indicate the potential anticancer activity [26]. Manikandan et al. prepared silver nanoparticles using aqueous extract of *Phyllanthus acidus* fruits from aqueous silver nitrate solution and investigate their possible role in cytoprotection and anti-inflammation. They find that silver nanoparticles possess potent anti-inflammatory activity by scavenging nitric oxide and superoxide anions [27]. Syafiuddin et al. The silver ions were reduced to silver nanoparticles by using biochemical contents present within *Cyperus rotundus*, *Eleusin indica*, *Melastoma malabathricum*, *Euphorbia hirta*, *Clidemia hirta*, and *Pachyrhizus erosus* extracts. Prepared silver nanoparticles were evaluated for antibacterial capability against *E. coli*, *B. cereus*, and rare bacterium *Chromobacterium haemolyticum*. They found that all silver nanoparticles have antibacterial capability [28]. Pandian et al. synthesized silver nanoparticles using *Allium sativum* extract and evaluated by cytotoxic assays. Surprisingly, prepared silver nanoparticles have enhanced cytotoxic effect and induced many apoptotic cells even with lower concentrations. However, silver nanoparticles are cytotoxic to normal cell line (VERO cells) at higher concentrations, but careful use with lower concentrations can make silver nanoparticles an efficient anticancer agent [29]. Prabhu et al. synthesized silver nanoparticles using leaf extract of *Vitex negundo* as a potential antitumor agent using human colon cancer cell line HCT15. Silver nanoparticles were able to arrest HCT-15 cells at G_0/G_1 and G_2/M phases with a decrease in S phase. Results suggest that silver nanoparticles may exert their antiproliferative effect on colon cancer cell line by suppressing its growth, reducing DNA synthesis, arresting G_0/G_1 phase, and inducing apoptosis [30]. Silver nanoparticles were synthesized by Ramar et al. using unripe fruit extract of *Solanum trilobatum* and evaluated for antibacterial activity against few human pathogenic bacteria (*Streptococcus mutans*, *Enterococcus faecalis*, *Escherichia coli*, and *Klebsiella pneumonia)* as well as anticancer activity against human breast cancer cell line (MCF-7) using MTT, nuclear morphology assay, Western blot, and RT-PCR expression. Results revealed that prepared silver nanoparticles have potential antibacterial and anticancer activities [31]. Silver nanoparticles were evaluated for their effect on growth and health of broiler chickens after infection with *Campylobacter jejuni*, and results revealed that concentration of 50 ppm in drinking water reduces broiler growth and impairs immune functions while having no any antibacterial effect [32].

Sankar et al. prepared silver nanoparticles using the aqueous extract of *Origanum vulgare* by reducing 1 mm silver nitrate solution. They evaluated prepared silver nanoparticles for antibacterial and anticancer efficacy. Silver nanoparticles were found to have an impressive inhibiting effect on human pathogens (*Aeromonas hydrophila*, *Bacillus* spp., *Escherichia coli*, (enteropathogenic—EP), *Klebsiella* spp., *Salmonella* spp., *Salmonella paratyphi*, *Shigella dysenteriae*, and *Shigella sonnei*) as well as a cytotoxic effect against human lung cancer A549 cell line [33]. Sun et al. prepared fabricated silver nanoparticles combined with quercetin, which were stabilized by using a layer of molecules, that is, siRNA, and found that the prepared silver nanoparticles have potential activity against *B. subtilis* [34]. Li et al. synthesized silver nanoparticles by reduction of aqueous silver ion with culture

supernatants of *Aspergillus terreus*, and prepared silver nanoparticles showed excellent antimicrobial activity against *Candida albicans*, *Candida krusei*, *Candida parapsilosis*, *Candida tropicalis*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli* [35].

Rajeswari et al. synthesized silver nanoparticles using *Aspergillus* consortium consisting of *Aspergillus niger*, *Aspergillus michelle*, and *Aspergillus japonicus* and evaluated them for anticancer activity against MCF-7 cell line by MTT assay. Results revealed that prepared silver nanoparticles were capable for 100% cell inhibition at 25, 50, and 100 μg concentrations. However, the lowest IC_{50} = 1.47 μg/ml was found for nanoparticles produced from *Aspergillus japonicus* [36]. Sayed et al. synthesized silver nanoparticles using *Aspergillus terreus* cell-free filtrate and evaluated them for antibacterial activity against *Staphylococcus aureus* (MRSA), *Shigella boydii*, *Acinetobacter baumannii*, *Shigella sonnei*, and *Salmonella typhimurium*. They find that prepared silver nanoparticles have potential activity against all the strains [37]. Singh et al. prepared silver nanoparticles using endophytic fungus, *Penicillium* sp., isolated from healthy leaves of *Curcuma longa* and evaluated them against MDR *E. coli* and *S. aureus*. Results revealed that prepared silver nanoparticles have good antibacterial activity with a maximum zone of inhibition of 17 and 16 mm at 80 μL concentration, respectively [38]. Ramalingmam et al. used endophytic fungus *Curvularia lunata* for the extracellular biosynthesis of silver nanoparticles from silver nitrate solution, and prepared silver nanoparticles were tested for antimicrobial potential against *E. coli*, *Pseudomonas aeruginosa*, *Salmonella paratyphi*, *Bacillus subtilis*, *Staphylococcus aureus*, and *Bacillus cereus*. Results revealed that prepared silver nanoparticles have potential antimicrobial activity against all strains [39]. Muhsin et al. synthesized silver nanoparticles using endophytic fungus *Papulaspora pallidula* and evaluated them for antitumor efficacy against human larynx carcinoma cell line (HEp-2). They also investigate them against human pathogenic bacteria (*Escherichia coli*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Staphylococcus aureus*) for antibacterial activity using agar well diffusion technique. Results revealed that prepared silver nanoparticles have high inhibition potential against HEp-2 cell line and are effective against all pathogenic bacteria under screening [40].

Arun et al. developed silver nanoparticles using a mushroom fungus *Schizophyllum commune* and evaluated them for their antimicrobial activity against bacterial (*Escherichia coli*, *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Klebsiella pneumonia*) as well as fungal (*Trichophyton simii*, *Trichophyton mentagrophytes*, and *Trichophyton rubrum*) pathogenic strains. They also investigate their anticancer activity using MTT cytotoxicity assay on human epidermoid larynx carcinoma (HEp-2) cell lines. Results revealed that prepared silver nanoparticles have a significant antimicrobial as well as anticancer activity [41]. Barapatre et al. prepared silver nanoparticles by enzymatic reduction of silver nitrate using two lignin-degrading fungi, that is, *Aspergillus flavus* and *Emericella nidulans*, and evaluated them for antibacterial activity against *Escherichia coli* and *Pseudomonas aeruginosa* as well as against *Staphylococcus aureus*. The antibiofilm potential was also tested. They found that prepared silver nanoparticles are effective against tested pathogenic microbes and have the ability to inhibit the biofilm formation by 80–90% [42]. Extracellular synthesis of silver nanoparticles from *Phoma glomerata* was done by Birla et al. and investigated for antibacterial efficacy against *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. They found that antibiotics showed remarkable sensitivity when used in combination with prepared silver nanoparticles [43].

Subbaiya and Selvam synthesized silver nanoparticles by *Streptomyces olivaceus* and evaluated them for their anticancer potential against non-small cell lung carcinoma cell line (NCI-H460). They found that prepared silver nanoparticles

were effective against the cancer cell line [44]. Silver nanoparticles synthesized using aqueous extract of *Agaricus bisporus* fungi were tested for cytotoxic effect on MCF-7 breast cancer cells by El-Sonbaty who found that prepared silver nanoparticles have a dose-dependent cytotoxic effect on MCF-7 breast cancer cells with LD_{50} (50 μg/ml). He also found that silver nanoparticles have a synergistic effect in cancer therapy with gamma radiation [45]. Gade et al. synthesized silver nanoparticles by *Aspergillus niger* isolated from soil and evaluated them for antimicrobial potential. They found that prepared silver nanoparticles have remarkable antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*, respectively [46]. Endophytic fungal species, *Penicillium* species from *Glycosmis mauritiana*, was used for the synthesis of silver nanoparticles by Govindappa et al and evaluated for their biological potential. They found that prepared silver nanoparticles have anti-inflammatory, xanthine oxidase, and lipoxygenase and tyrosine kinase inhibitory activity. Furthermore, prepared silver nanoparticles strongly inhibit bacterial species like *E. coli* and *P. aeruginosa* [47].

Rajam et al. prepared silver nanoparticles using fungus *Emericella nidulans* EV4 and investigated their potential against *Pseudomonas aeruginosa* NCIM 5029. They found that prepared silver nanoparticles showed remarkable control over the growth of *Pseudomonas aeruginosa* NCIM 5029 [48]. Kulkarni et al. synthesized silver nanoparticles using *Deinococcus radiodurans* and found that prepared silver nanoparticles have remarkable antimicrobial, anticancer, and anti-biofouling activity [49]. Netala et al. prepared silver nanoparticles by using the aqueous culture of filtrate from *Pestalotiopsis microspora* and evaluated them for antioxidant and anticancer potential. Prepared silver nanoparticles showed remarkable radical scavenging activity against DPPH and H_2O_2 radicals with IC_{50} values of 76.95 ± 2.96 and 94.95 ± 2.18 μg/ml as well as significant cytotoxic effect against SKOV3 (human ovarian carcinoma, IC_{50} = 16.24 ± 2.48 μg/ml), B16F10 (mouse melanoma, IC_{50} = 26.43 ± 3.41 μg/ml), PC3 (human prostate carcinoma, IC_{50} = 27.71 ± 2.89 μg/ml), and A549 (human lung adenocarcinoma, IC_{50} = 39.83 ± 3.74 μg/ml) cells, respectively [50]. Silver nanoparticles prepared by using the cell-free extract of *Saccharomyces boulardii* were tested for anticancer activity against breast cancer cell lines (MCF-7 cells) by Kaler A. et al. who found that silver nanoparticles showed very high activity on MCF-7 cells, showing 80% inhibition [51]. Durairaj et al. synthesized silver nanoparticles using *Penicillium notatum* and evaluated them for their antibacterial and larvicidal potential in mosquitoes. They found that silver nanoparticles have significant mortality rate against second and third instar larvae of *Culex quinquefasciatus* after 24 h exposure and were effective against *Staphylococcus aureus*, *Escherichia coli*, *Salmonella Shigella*, and *Salmonella typhimurium*, respectively [52]. Silver nanoparticles prepared by using culture supernatants of *Aspergillus terreus* were evaluated for their antimicrobial properties by Li et al. and found to have broad-spectrum antimicrobial activity against *A. terreus* against *P. aeruginosa*, *S. aureus*, *E. coli*, *C. albicans*, *C. krusei*, *C. glabrata*, *C. tropicalis*, *A. fumigatus*, and *A. flavus*, respectively [35]. Ma et al. prepared silver nanoparticles using cell-free filtrate of the fungus strain *Penicillium aculeatum* Su1 as reducing agent and found that prepared nanoparticles exhibit higher antimicrobial activity against *E. coli*, *P. aeruginosa*, *S. aureus*, *B. subtilis*, and *C. albicans* as well as have higher biocompatibility toward human bronchial epithelial (HBE) cells with high cytotoxicity in dose-dependent manner (IC_{50} = 48.73 μg/ml) toward A549 cells [53].

Silver nanoparticles were prepared using culture supernatant of *Nocardiopsis* sp. MBRC-1 and evaluated for antimicrobial and anticancer activity by Manivasagan et al. Results revealed that silver nanoparticles have strong antimicrobial activity against bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Enterococcus hirae*, *Shigella flexneri*, and *Staphylococcus aureus*) and fungi (*A. brasiliensis*, *A. fumigatus*,

Aspergillus niger, and *Candida albicans)* and are effective against human cervical cancer cell line (HeLa) in dose-dependent manner with IC_{50} value of 200 μg/ml, respectively [54]. Silver nanoparticles were synthesized by Rahimi et al. using biomass obtained from the culture of *Candida albicans* and evaluated for antibacterial properties. Results revealed that prepared silver nanoparticles were effective against *Escherichia coli* and *Staphylococcus aureus* [55]. Rajora et al. used textile soil-isolated bacterium *Pseudomonas stutzeri* to synthesize silver nanoparticles and evaluated them for their antimicrobial and cytotoxicity properties. Results revealed that prepared silver nanoparticles have strong antibacterial activity against multidrug-resistant (MDR) *Escherichia coli* and *Klebsiella pneumonia* and do not have any cytotoxic effects on human epithelial cells [56]. Shanmugasundaram et al. isolated an actinobacterium, *Streptomyces* sp. M25, and used its biomass for the synthesis of silver nanoparticles. Prepared silver nanoparticles when evaluated for larvicidal activity were found to have significant activity against malarial vector, *Anopheles subpictus* (LC_{50} = 51.34 mg/l) and filarial vector *Culex quinquefasciatus* (LC_{50} = 60.23 mg/l), respectively [57].

Kalaivani et al. prepared silver nanoparticles using *Lactobacillus acidophilus* and white rot fungus (*Pleurotus platypus*) and found that prepared silver nanoparticles were effective when evaluated for antibacterial potential against pathogenic bacterial strains such as *Bacillus subtilis*, *Escherichia coli*, and *Staphylococcus aureus*, respectively [58]. Silver nanoparticles prepared by using *Aspergillus clavatus* (AzS-275), an endophytic fungus isolated from sterilized stem tissue of *Azadirachta indica* A. Juss, were evaluated for antimicrobial potential and found effective against *Candia albicans* (MIC = 9.7 μg/ml, inhibition zone = 16 mm), *Pseudomonas fluorescens* (inhibition zone = 14 mm), and *Escherichia coli* (inhibition zone = 10 mm), respectively [59]. Waghmare et al. prepared silver nanoparticles using *Candida utilis* NCIM 3469 and evaluated them for antibacterial potential. Results revealed that prepared silver nanoparticles were effective against pathogenic organisms such as *Pseudomonas aeruginosa* (inhibition zone = 13 ± 1.2 mm), *Staphylococcus aureus* (inhibition zone = 8 ± 0.8 mm), and *Escherichia coli* (inhibition zone = 10 ± 1.0 mm), respectively [60].

4.2 Physical applications

4.2.1 Fabrication of antennas

Alshehri et al. have prepared two samples: the first was fabricated from the nano-metallic silver, and the second consists of micrometer-sized grains. Both types were prepared using thick-film fabrication process. The material involved in sample preparation was fine metal powder, an inorganic binder-like metal oxide, and an organic vehicle that evaporates during the initial drying stages. Both the samples were characterized for the electrical performances. They found that in the lower-frequency range, both types of conductors (samples) behave similarly with electrical loss but increase approximately linearly with increased frequency range (from 0.1 dB/mm/GHz up to 80 GHz), but above 80 GHz frequency, the silver nanoparticle-fabricated sample showed lower electrical loss, and this behavior continues up to the above whole frequency range. The lower level of the loss from the silver nanoparticle conductors and the overall trend in loss per wavelength do not depend significantly on frequency. Therefore, it has been concluded that the silver nanoparticle-fabricated conductors show a less electrical loss at high-frequency range which in turn attributed to lower surface roughness found in the nanoparticles due to better packing and may open opportunities for low-temperature fabrication of antennas and for sub-THz metamaterials with improved performance [61].

4.2.2 In electronically conductive adhesives

Silver nanoparticles can be used as a silver paste in the electrodes because of their high conductivity. They have also been used as conductive fillers in electronically conductive adhesives (ECAs). Chen et al. have synthesized the silver nanoparticles by reducing the silver nitrate with ethanol in the presence of polyvinylpyrrolidone (PVP). Various reaction conditions have been studied such as PVP concentration, reaction time, and reaction temperature. In this method, PVP prevents the aggregation; in addition to this, the PVP increases the rate of spontaneous nucleation and decreases the mean size of silver nanoparticles. The ethanol used in this has been employed as a reducing agent or diluent to adjust the viscosity of the ECAs. The resulting silver nanoparticles obtained with chemical reduction method had very fine dispersion and narrow size distribution. The ECAs had the silver nanoparticles re-dispersed in the ethanol. The absorption peak was determined at 410 nm which was a clear signature of the quantum size effect occurring in the absorption property of silver nanoparticles. It has also been concluded that the particle size of nanoparticles has been decreased with increasing concentration of silver nitrate and with increasing reaction temperature, but with increasing reaction time, the size of nanoparticles has been increased [62]. Yang et al. have prepared silver nanoparticles, silver nanorods, and epoxy resins containing high-performance electrically conductive adhesives (ECAs) using a novel preparation method. The prepared nanoparticles and nanorods were dispersed well, and there was no agglomerate in the matrix. The volume electrical resistivity tests showed the volume electrical resistivity of the ECA was closely related with the various sintering temperatures and time and time and the ECA could achieve the volume electrical resistivity of (3–4) $\times$ 9 10^{-5} Ω after sintering at 160°C for 20 min. They found that the prepared ECA was able to achieve low-temperature sintering and possessed excellent electrical, thermal, and mechanical properties [63]. This offers the possibility to effectively use these synthesized nanoparticles for improving the conductivity of ECAs.

4.2.3 Ink-jet printing

The silver nanoparticles can be used in ink-jet printing. Wu and Hsu have synthesized the silver nanoparticles by chemical reduction from the silver nitrate using triethylamine as reducing and protecting agent. After that the nanoparticles have been sintered using the process involved cleaning it with acetone and deionized water to remove the particles and organic contaminants on the surface; after cleaning the film, it was treated with ozone by UVO-100 UV ozone for 30 min. The silver nanoparticle suspensions were spin coated (500 rpm, 15 s) on the polyimide substrate and dried at room temperature in order to remove the solvent. The resulting silver nanoparticles on the polyimide substrate were heated from 100 to 200°C and held at 200°C for 1 h in order to convert to silver films. The polyimide substrate was then naturally cooled at room temperature in the glass dish. The above synthesized silver nanoparticles were sintered at different temperatures, and it was found that the resistivity of the silver film sintered at 150°C for 1 h was close to the resistivity of bulk silver. Based on the above data, the synthesized nanoparticles had the low sintering temperature; hence, the silver nanoparticle suspensions could be used to fabricate the flexible electronics by ink-jet printing [64].

4.2.4 Fillers

The micro-sized silver particle fillers appear as the full-density silver flakes, and the silver nanoparticles fillers appear to be the highly porous agglomerates (similar

to open-cell foams). Ye measured/analyzed the distribution of different sized particles using TEM. The electrical resistivity was also measured which was compared with the different levels of filler loading. The silver nanoparticles were prepared using the nano-sized spheres of size approximately 50–150 nm in diameter, micro-sized particles with a diameter of 5–8 μm, and flakes of silver of 10 μm in length. By TEM studies of the distribution of silver particles in micro-sized particle sea, it was concluded that it is difficult to find the cross-linkage of particles and there are fewer chances of different contact and contact area, and by the resistivity measurements, it has been revealed that the conductivity of micro-sized silver particle-filled adhesive is dominated by constriction resistance, the silver nanoparticle-containing adhesive is controlled by tunneling and even thermionic emission, and hence the respective nanoparticles are used to increase the electrical conductivity [65].

4.2.5 Water treatment

Dankovich prepared silver nanoparticles in a paper using microwave irradiation. Antibacterial activity and silver release from the silver nanoparticle sheets were assessed for model *Escherichia coli* and *Enterococcus faecalis* bacteria in deionized water and in suspensions that also contained with various influent solution chemistries, that is, with natural organic matter, salts, and proteins. The paper sheets containing silver nanoparticles were effective in inactivating the test bacteria as they passed through the paper. The resultant silver nanoparticle paper is just as effective for inactivating bacteria during percolation through the sheet; the silver nanoparticle papers effectively purify water contaminated with bacteria. Hence, in conclusion, the paper incorporated with silver nanoparticles by microwave has been used for the purification of contaminated water [66]. Park et al. developed micrometer-sized silica hybrid composite decorated with silver nanoparticles, that is, AgNP-SiO_2 (to prevent the inherent aggregation of silver nanoparticles and easy recovery from environmental media after utilization), and evaluated them for antiviral activity using bacteriophage MS2 and murine norovirus (MNV) models. Results revealed their potential, and it was concluded that developed silver nanoparticles (AgNP-SiO_2) can be efficiently used in disinfection processes for inactivation of various waterborne viruses [67]. Abu-Elala et al. investigated the effect of chitosan-silver nanocomposite on fish crustacean parasite, *Lernaea cyprinacea*, disease found in goldfish (*Carassius auratus*) aquaria during the spring season. Their results proposed that chitosan silver nanocomposite is efficient in parasitic control in ornamental glass aquaria [68].

4.2.6 Solar cell optimization

Plasmonic effects in thin film silicon solar cell are an emerging technology and area of rigorous research for the researchers from the past couple of years. It has promising application in solar cell fabrication industries where it uses nanoscale properties of silver nanoparticles incorporated in the interface between the metal and dielectric contacts that enhance the light-trapping properties of thin film silicon solar cells by increase absorbance capacity and generation of hot electrons that enhance the photocurrents in the solar cell. Sangno et al. had taken two different thicknesses of the silver thin film (made of silver nanoparticles) of 5.9 and 7.8 nm in 2×10^{-4} (Torr) and 2.5×10^{-4} (Torr) pressure environment for investigation purpose. Samples were annealed at different temperature ranges for a definite time period under vacuum condition of 4.5×10^{-6} Torr. They found that reflectance reduces 13–11% due to plasmonic effect and enhancement in the conversion efficiency of the solar cell [69].

4.2.7 Biosensor fabrication

Li et al. fabricated nanoenzymatic glucose biosensors by depositing silver nanoparticles using in situ chemical reduction method on TiO_2 nanotubes which were synthesized by the anodic oxidation process. The structure, morphology, and mechanical behaviors of the electrode were examined by scanning electron microscopy and nanoindentation. It was found that silver nanoparticles remained both inside and outside of TiO_2 nanotubes whose length and diameter were about 1.2 μm and 120 nm. The composition was constructed as an electrode of a non-enzymatic biosensor for glucose oxidation. The electrocatalytic properties of the prepared electrodes for glucose oxidation were investigated by cyclic voltammetry (CVs) and differential pulse voltammetry (DPV). When compared with bare TiO_2 and silver-fresh TiO_2 nanotube, Ag-TiO_2/(500°C) nanotube exhibited the best electrochemical properties from cyclic voltammetry (CVs) results. In addition, the nonenzymatic glucose sensors exhibited excellent selectivity, stability, and repeatability. Nanoenzymatic glucose biosensors have potential application in catalysis and sensor areas [70]. Ruth et al. has synthesized the oligonucleotide-silver nanoparticle (OSN) conjugates and revealed their use with magnetic beads as a biosensor for *Escherichia coli* detection under the magnetic field condition. The biosensor developed was able to detect the presence of DNA target which was isolated from the three isolation methods, and it has been found that best detection signals were achieved by the isolation method in which it could detect the presence of DNA target up to 1.3 ng/μl [71]. Mahmudin et al. synthesize the silver nanoparticles by chemical reduction method. TEM images showed that morphology of silver nanoparticles had spherical geometry and had dispersive particle distribution. They conclude that this type of dispersibility of nanoparticles such as this could potentially be used as an active ingredient of SPR biosensor [72]. Sistani et al. have developed the enzymatic biosensor for selective detection of penicillin by using silver nanoparticles, and sensor configuration showed the linear dynamic range for output response vs. logarithmic concentration of a salt solution of penicillin G [73].

4.2.8 Protein sensing

Tung N.H reported that silver nanoparticles labeling could be used in protein sensing studies by liquid electrode plasma-atomic emission spectrometry (LEP-AES). This technique is suitable for on-site portable analysis because plasma gas and the high-power source are not required. Proposed detection method could have a wide variety of promising applications in metal nanoparticle-labeled biomolecule detection [74].

4.2.9 Hospitals

Duran et al. prepared silver nanoparticles by using *Fusarium oxysporum* and studied their antimicrobial effect when incorporated in cotton fabrics against *Staphylococcus aureus*. They found that fabric incorporated with silver nanoparticles have significant antibacterial activity. They proposed that clothes with silver nanoparticles are sterile and can be useful in hospitals to prevent or to minimize infection with pathogenic bacteria such as *Staphylococcus aureus* [75].

4.2.10 Analytical

Lipids are the major components of cell membrane and abnormal cellular metabolism-induced lipid changes. Hua et al. investigate silver nanoparticle-induced lipid

changes on the surface of macrophage cells using time-of-flight secondary ion mass spectrometry (ToF-SIMS). By using this technique, one can understand the mechanism of cell-nanoparticle interactions at the molecular level and characterize the changes in lipids on the single cell surface [76]. Citrate- and polyethyleneimine-coated silver nanoparticles can be used to understand how the type of capping agents and surface charge affects their colloidal stability, dissolution, and ecotoxicity in the absence/presence of Pony Lake fulvic acid (PLFA). On the basis of this, Jung et al. demonstrate that the differences in colloidal stability, ecotoxicity, and dissolution may be attributed to different capping agents, surface charge, and natural organic matter concentration as well as to the formation of dissolved silver complexes with natural organic matter [77].

4.2.11 Agricultural and marine

Silver nanoparticles synthesized by Guilger et al. using fungus *Trichoderma harzianum* were evaluated for cytotoxicity and genotoxicity against fungus *Sclerotinia sclerotiorum* which is responsible for the agricultural disease white mold and found that nanoparticles showed potential against *Sclerotinia sclerotiorum*, inhibiting sclerotium germination and mycelial growth. The study suggests that silver nanoparticles can be a new alternative in white mold control [78]. Babu et al. have synthesized silver nanoparticles in vitro using marine bacteria *Shewanella algae bangaramma* and found that the synthesized nanoparticles have both larvicidal and bactericidal activities and no mortality in control; in addition to this, the maximum values of LC_{50} and LC_{90} with 95% confidential limit [4.529 mg/ml (2.478–5.911), 9.580 mg/ml (7.528–14.541)] were observed with third instar larvae of *Lepidiota mansueta* (Burmeister). It was found that the mortality of larvae was significantly increased in all the concentrations ($P < 0.0001$) in all the exposed groups. The bactericidal activities of the silver nanoparticles were determined against some of the bacterial species which followed the following order: *Vibrio cholera* < *Roseobacter* spp. < *Alteromanas* spp. It has been concluded that the synthesized silver nanoparticles had effective larvicidal and antifouling activities and can be effectively used in the agricultural and marine pest control [79].

4.2.12 Miscellaneous

Chen prepared silver nanoparticles from filamentous fungus *Phoma* sp3.2883 via adsorption and accumulation as well as proposed that fungus *Phoma* sp3.2883 is a potential biosorbent that can be used for the production of silver nanoparticles and would be useful in waste detoxification and in silver recovery programs [80]. Du et al. synthesized silver nanoparticles under light radiation using cell filtrate of *Penicillium oxalicum* 1–208. The prepared silver nanoparticles were used as a catalyst and exhibit excellent catalytic activity for reduction of methylene blue in the presence of $NaBH_4$ at ambient temperature [81]. Otari et al. synthesized silver nanoparticles using culture supernatant of phenol degraded broth (prepared by using an actinobacterium *Rhodococcus* NCIM 2891) and investigate their catalytic potential. They found that prepared silver nanoparticles have excellent catalytic activity in the reduction of 4-nitrophenol to 4-aminophenol by $NaBH_4$ [82]. Zaheer synthesized silver nanoparticles using an aqueous extract of date palm fruit pericarp and evaluated them for antimicrobial activity against multiple drug-resistant *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans*. Results revealed that inhibition was concentration dependant. It was also concluded that silver nanoparticles have good catalytic activity toward the catalytic and photocatalytic degradation of 4-nitrophenol [83]. Soni et al. prepared silver nanoparticles using soil fungus *Aspergillus niger* 2587 and evaluated them against larvae and pupae of *Anopheles stephensi*, *Culex*

quinquefasciatus, and *Aedes aegypti*. Results revealed that larvae of *Culex quinquefasciatus* were most susceptible and showed 100% mortality after 1 h of exposure. This suggests the possible application of silver nanoparticles in mosquito control [84]. Larvicidal potential of silver nanoparticles synthesized by using filamentous fungus *Cochliobolus lunatus* was determined against vectors *Aedes aegypti* and *Anopheles stephensi* by Salunkhe et al. They found that silver nanoparticles have efficacy against the second, third, and fourth instar larvae of *A. stephensi* (LC_{50} 1.17, 1.30, and 1.41; LC_{90} 2.99, 3.13, and 3.29 ppm) and against *A. aegypti* (LC_{50} 1.29, 1.48, and 1.58; LC_{90} 3.08, 3.33, and 3.41 ppm). They also proposed that possible larvicidal activity may be due to the penetration of nanoparticles through the membrane [85]. Sanago et al. investigated silver nanoparticles synthesized by using filamentous fungus *Penicillium verrucosum*, for larvicidal activities against the filarial vector *Culex quinquefasciatus*. They find that synthesized silver nanoparticles were effective against the first, second, third, and fourth instar larvae and pupae of *Culex quinquefasciatus* with LC_{50} (LC_{90}) values of 4.91 (8.13), 5.16 (8.44), 5.95 (7.76), and 7.83 (12.63) at 25 ppm as well as 5.24 (8.66), 5.56 (8.85), 6.20 (10.01), 7.04 (10.92) and 7.33 (11.59) at 50 ppm in larval instars and pupae [69]. Silver nanoparticles were prepared by Suresh et al. using an aqueous extract of *Delphinium denudatum* and evaluated for their larvicidal (against second instar larvae of the dengue vector *Aedes aegypti*) potential. They found that prepared silver nanoparticles have potent larvicidal activity with LC_{50} value of 9.6 ppm [86].

5. Conclusion

It is revealed that silver nanoparticles have potential applications in therapeutics as well as in other physical fields. In therapeutics, researchers are seemed to be more focused on anticancer and antimicrobial evaluations. Green synthesis makes them eco-friendly and nonhazardous. Applications of silver nanoparticles are not limited to therapeutics only, they are equally covering physical fields too such as biosensors and antenna fabrication, conductive adhesives, in ink-jet printing, water treatment, solar cell optimization, protein sensing, etc. Rigorous research has been carried out and continued on this nanostructure. Therefore, the silver nanoparticle has the ability to be a lead nanoparticle of the future due to its wide variety of applications.

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