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REVIEW PAPER

# Applications of Silver nanoparticles in diverse sectors

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**Abstract**

The review article summarizes the applications of silver nanoparticles for diverse sectors. Over the decades, nanoparticles used as dignified metals such as silver exhibited distinctive characteristics basically correlated to chemical, physical and biological property of counterparts having bulkiness. Numerous studies reported that Nanoparticles of about 100 nm diameter play a crucial role in widely spread industries due to unique properties including the dimension of small particle, high surface area and quantum confinement and they dispersed without agglomeration. Decade of discoveries clearly established that shape, size and distribution of Silver nanoparticles strongly affect the electromagnetic, optical and catalytic properties, which are often an assortment of changeable synthetic methods and reducing agents with stabilizers. Generation after generation the postulates come forth about properties of silver for the ancient Greeks cook from silver pots and the old adage 'born with a silver spoon in his mouth' thus show that eating with a silver spoon was well-known as uncontaminated. Impregnation of metals with silver nanoparticles is a practical way to exploit the microbe aggressive properties of silver at very low cost. The nanoparticles help in targeted delivery of drugs, enhancing bioavailability, sustaining drug or gene effect in target tissues, and enhancing the stability. Implementations of silver partials in medical science and biological science have been noticed from years ago; however alteration with nanotechnology is innovative potential. Over 23% of all nanotechnology based products, diagnostic and therapeutic applications implanted with silver nanoparticles (e.g. In arthritic disease and wound healing, etc.) and widely known for their antifungal, antibacterial, antiviral effect, employed in textile fabrics and added into cosmetic products as antiseptic to overcome skin problems. Thus, Silver nanoparticles (AgNPs) have been urbanized as an advanced artifact in the field of nanotechnology.

**Keywords:** *Antimicrobial Activity, Biofilm Forming, Nanosilver, Silver Nanoparticles, Staphylococcus Aureus*

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## INTRODUCTION

The inimitable properties of Silver nanoparticles make them interesting for commercial and scientific appliance as an antimicrobial, disinfectant, biosensor materials, composite fibers, cryogenic superconducting materials, cosmetic products, and electronic components. Numerous physical and chemical methods are used for synthesizing and stabilizing silver nanoparticles [1, 2]. The highly accepted chemical approaches were employed to synthesis silver nanoparticles that include chemical reduction, using a variety of inorganic and organic reducing agents, physicochemical reduction, electrochemical techniques, and radiolysis. Recently, nanoparticles synthesis had been the foremost fascinating scientific areas of inquiry and there's growing attention to supply eco-friendly exploitation of nanoparticles (green chemistry). Green chemistry approaches comprise mixed-valence polyoxometalates, Tollens, polysaccharides, irradiation and biological method that have advantages over conventional methods concerning chemical agents associated with environmental toxicity. Antimicrobial property of silver nanoparticles expresses the relevance to the medical field for investigations and curative applications and needed by humans in everyday life [3]. The Silver nanoparticle replacing the weak

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antibacterial agents involve in water disinfection, textile industry, medical and food packaging, etc. They might also be involved in neutralizing these adhesive substances, thus preventing biofilm formation [4].

Presently, nanochemistry becomes a rising directions of Nanoscience [5]. The nanometer-size metallic particles show unique and significantly changed physical, chemical and biological properties comparison of macro-scaled counterpart based on their high surface-to-volume ratio. These nanoparticles exhibit size and shape-dependent properties as catalysts and sensing to optics, antibacterial activity and data storage [6-9]. For instance, the antimicrobial activity of diverse metal nanoparticles, including silver colloids is closely associated with their size; that is, the smaller the silver nuclei, the greater and therefore the antibacterial activity. Moreover, the catalytic activity of these nanoparticles is also dependent on their size as well as their structure, shape, size distribution, and chemical-physical environment. To overcome the irregular size distribution, specific management of form, size, and size distribution is achieved by different strategies of synthesis, reducing agents and stabilizers [10-12]. The optical properties of a metal-bearing nanoparticle principally based on its surface plasmon resonance, where the Plasmon is the collective oscillation of the free electrons within the metal-bearing nanoparticle. It is renowned that the Plasmon resonant peaks and line widths are sensitive to the size and forms of the nanoparticle, the metallic species and the surrounding medium. For instance, nanoclusters composed of 2-8 silver atoms might be best for a replacement of optical knowledge storage. Moreover, fluorescent emissions through clusters, may exploit at biological labels and electroluminescent displays [13-14]. Recently, AgNPs become interesting for therapeutic applications of cancer as metastatic tumor agents, in diagnostics and in inquiring, thus the review explore the mechanism of metastatic tumor activity, therapeutic approaches and the limitations of nanoparticles in cancer medical aid. The Silver nanoparticles are also effective against a broad spectrum of gram-negative and gram-positive bacteria, together with some antibiotic-resistant strains [15]. The cluster of gram-negative bacteria, against which the biocide activity of silver nanoparticles has been confirmed, includes: *Acinetobacter* [16], *Escherichia* [17], *Pseudomonas* [18] and *Salmonella* [19]. The effective action of silver nanoparticles was also reportable against gram-positive bacteria: *Bacillus* [20], *Enterococcus* [21], *Listeria* [22], *Staphylococcus* [23] and *Streptococcus* [24]. Recent studies have shown that the use of silver nanoparticles in combination with certain antibiotics such as penicillin G, amoxicillin, erythromycin, clindamycin and vancomycin, creates a synergy effect against *E. coli* and *S. aureus* [25]. Few studies had also shown that silver nanoparticles may also be an efficient weapon against viruses [26] thus inhibiting their replication. Their activity has been confirmed even against the HIV-1 [27] and influenza virus [28]. The potency of processes resulting in the destruction of viruses strictly depends on the shape and size of nanoparticles [27]. The Silver nanoparticles are effective and fast-acting agent that destroys differing types of fungi like *Aspergillus* [29], *Candida* [30] and S*accharomyces* [15].

It focused on the overview on the Advantages of silver nanoparticles. The aim of this review is, therefore, to reflect on the advantages of silver nanoparticles and future prospects, especially the potential applications of the nanoparticles for pharmaceutical industries. Moreover, we explore the applications of silver nanoparticles in all respective sectors and their mechanistic aspects of silver nanoparticles as an antimicrobial agent.

## Applications of AgNPs in various sectors

AgNPs are broadly applicable as anti-bacterial agents for the food storage, health industry, textile coatings and a variety of environmental applications. The Products prepared by or from AgNPs have been permitted by a range of accredited bodies, including the US FDA, US EPA, SIAA of Japan, Korea's Testing and Research Institute for Chemical Industry and FITI Testing and Research Institute [31-36]. As anti-bacterial agents, AgNPs were implemented in numerous applications ranged involving disinfecting medical devices, home appliances and water treatment [37-38]. Moreover, this inspired the textile industry to use AgNPs in numerous textile goods (Table 1 and Fig. 1).

## Significance of AgNPs Biomedical science

Owing the exceptional properties, AgNPs have been used extensively in household implements, the health care industry, for food storage, environmental and biomedical applications. Several reviews and book chapters have been dedicated to the assorted areas for application of AgNPs. Here, we explore the applications of AgNPs in numerous biological and medical science field, i.e medication, antifungal, antiviral, medicine, anti-cancer, and anti-angiogenic. Here, we utterly addressed previously-published seminal papers and conclude with current information and outcomes. A schematic diagram representing various applications of AgNPs is providing in Fig. 2.

***Antibacterial accomplishment-*** AgNPs emerge as a substitute of antibacterial agent and have the ability to overcome the bacterial resistance against antibiotics. Therefore, it is necessary to widen the use of AgNPs as antibacterial agents. Amid various promising nanomaterials, AgNPs appear as a potential medication negotiator because of their massive surface-to-volume ratios and crystallographic surface structure. The seminal paper account by Sondi and Salopek-Sondi [39] verified the antimicrobial activity of AgNPs against

Table 1: Applications of silver nanoparticles in different-different sectors.

| S. No | Fields | Application of AgNPs |
|---|---|---|
| 1 | Biomedical application | • Antibacterial accomplishment<br>• Antifungal accomplishment<br>• Antiviral accomplishment<br>• Anti-inflammatory accomplishment<br>• Anti-angiogenic activity<br>• Anticancer exploit |
| 2 | Texiles application | • UV rays blocking textile<br>• Medicinal Textiles and Devices |
| 3 | Food industry | • Nanotechnology and food packaging<br>• Food processing |
| 4 | Environmental treatment | • Air disinfection<br>• Water disinfection<br>✓ Drinking water disinfection<br>✓ Groundwater and biological wastewater disinfection |
| 5 | Pharmacological Applications | • Antimicrobial activity<br>• Larvicidal Activity<br>• Wound Healing property |
| 6 | Miscellaneous | • Water treatment<br>• Catalytic activity |

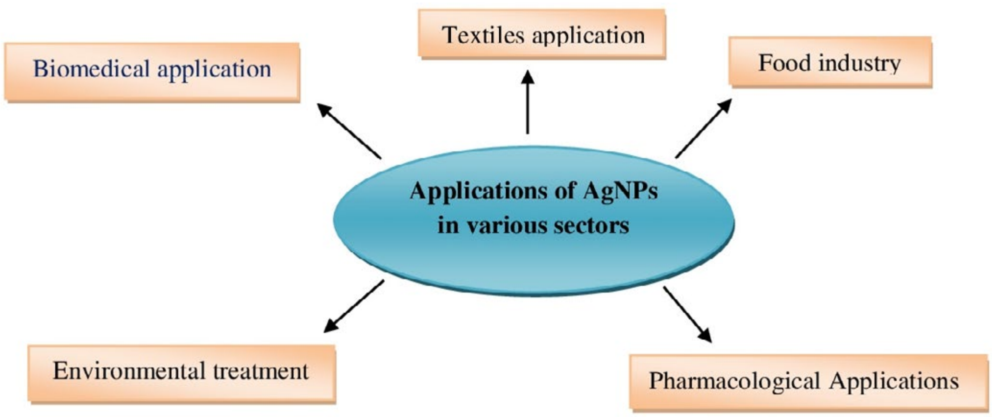


Fig. 1: Applications of silver nanoparticles in diverse sectors.

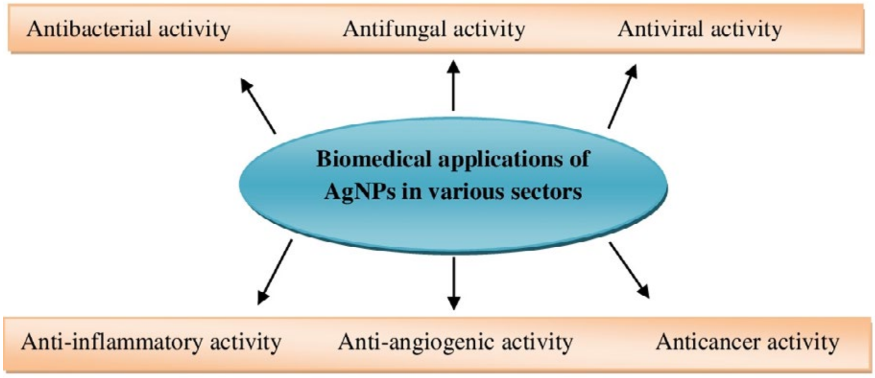


Fig. 2: Various biomedical applications of AgNPs.

*Escherichia coli* when *E. coli* cells treated with AgNPs showed the accretion of AgNPs into the cell wall and the formation of "pits" into the bacterial cell walls, and ultimately leading to cell death. In the same *E. coli* strain, smaller particles with a larger surface-to-volume ratio showed more efficient antibacterial activity than larger particles [40]. Furthermore, the antibacterial activity of AgNPs is not only the size, however also shape-dependent [41]. AgNPs were synthesize by four different types of saccharides with an average size of 25 nm, showing high antimicrobial and bactericidal activity against Gram-positive and Gram-negative bacteria, counting highly multi-resistant strains such as methicillin-resistant *Staphylococcus aureus*. As predicted previously, not only the size is important for determining the efficiency, however also shape is important for determining the efficiency, as AgNPs undergo a shape-dependent interaction with the Gram-negative organism *E. coli* [42]. Moreover, a detailed study was carried out to investigate the efficiency of the antimicrobial effects of AgNPs against yeast, *E. coli* and *Staphylococcus aureus* and concluded that, at low concentrations of AgNPs, the complete inhibition of growth was observed in yeast and *E. coli*, whereas a mild effect was observed for *S. aureus* [43]. Biologically synthesized AgNPs from the culture supernatants of *Klebsiella pneumoniae* were evaluated; the efficiencies of various antibiotics, such as penicillin G, amoxicillin, erythromycin, clindamycin, and vancomycin against *Staphylococcus aureus* and *E. coli* was increased with AgNPs [25]. On comparing with AgNPs, hydrogel-silver nanocomposites express excellent antibacterial activity against *E. coli*. One-pot synthesis of chitosan-Ag-nanoparticle composite was found to have higher antimicrobial activity than its components at their respective concentrations, because one-pot synthesis favors the formation of small AgNPs, attached to the polymer, that can be dispersed in media of pH≤6.3 [44]. Biologically produced AgNPs by means of culture supernatants of *Staphylococcus aureus,* illustrate significant antimicrobial activity against methicillin-resistant *S. aureus*, followed by methicillin-resistant *Staphylococcus epidermidis* (MRSE) and *Streptococcus pyogenes*, while only moderate antimicrobial activity was observed against *Klebsiella pneumoniae* and *Salmonella typhi* [45]. The mechanism of AgNP-induced cell death was observed in *E. coli* through the leakage of reducing sugars and proteins. Additionally, AgNPs have knack to demolish the permeability of the bacterial membranes via generating the pits and gaps, signifying that AgNPs could damage the structure of the bacterial cell membrane [17]. Silver nanocrystalline chlorhexidine (AgCHX) complex showed strong antibacterial activity against the tested Gram-positive/negative and methicillin-resistant *Staphylococcus aureus* (MRSA) strains. Fascinatingly, the minimal inhibitory concentrations (MICs) of nanocrystalline Ag (III) CHX were much lower than the ligand (CHX), $AgNO_3$, the gold standard and the silver sulfadiazine [46]. Biofilms are not only leads to antimicrobial resistance, but are involved in the development of ocular-related infectious diseases, such as microbial keratitis [47]. Kalishwaralal and co-workers demonstrated the potential anti-biofilmactivity against *Pseudomonas aeruginosa* and *Staphylococcus epidermidis*. Similarly, guava leaf extract reduced AgNPs (Gr-Ag-NPs) be evidence for significant antibacterial activity and stability against *E. coli* compared to chemically synthesized AgNPs; the reason for this higher activity could be the adsorption of biomolecules on the surface of the Gr-Ag-NPs [48]. AgNPs synthesized by Cryphonectria sp. prove antibacterial activity against numerous infective microorganism, as well as *E. coli,* S. *aureus, Candida albicans,* and *Salmonella typhi*. Interestingly, the AgNPs exhibited higher antibacterial activity against both *S. aureus* and *E. coli* other than *S. typhi* and *C. albicans*.

The AgNPs exhibit the prospective for anti-biofilm activity aligned with "*Pseudomonas aeruginosa"* and "*Staphylococcus epidermidis"*. Similarly, guava leaf extract reduced AgNPs (Gr-Ag-NPs) showed significant antibacterial activity and stability against *E. coli* in contrast to chemically synthesized AgNPs; the reason might be due to higher activity for adsorption of biomolecules on the surface of the Gr-Ag-NPs [48]. AgNPs synthesized by *Cryphonectria* sp. explain antibacterial activity against diverse human pathogenic bacteria, counting *S. aureus*, *E. coli*, *Salmonella typhi*, and *Candida albicans*. Interestingly, these particular AgNPs exhibited higher antibacterial activity against both *S. aureus* and *E. coli* than *S. typhi* and *C. albicans*.

***Antifungal accomplishment-*** Fungal infections are more frequent in patients with immuno-suppression and overcoming fungi-mediated diseases is a tedious process, because currently there is a limited number of antifungal drug [30]. Consequently, there is a foreseeable and insistent requirement to develop antifungal agent that should be biocompatible, non-toxic, and environmental friendly. To overcome the problem, AgNPs play an important role as anti-fungal agents against various diseases caused by fungi. Nano-Ag illustrates effective anti-fungal activity beside clinical isolate and "ATCC" strains of "*Trichophyton mentagrophytes"* and "*Candida"* species with concentrations of 1-7 µg/mL. Esteban-Tejeda et al. [49] developed an inert matrix containing AgNPs with a medium size of 20 nm into a soda-lime glass that increased the biocidal activity. Monodisperse Nano-Ag sepiolite fibers express significant antifungal activity against *Issatchenkia orientalis*. AgNPs exhibited excellent antifungal activity against *Aspergillus niger* with MIC of 25 µg/ml against *Candida albicans* [50]. Bio-synthetic AgNPs express superior antifungal activity with "fluconazole" against "*Phoma glomerata"*, "*Phoma herbarum"*, "*Fusarium semitectum"*, "*Trichoderma* sp.", and *Candida albicans* [51]. AgNPs stabilized by sodium dodecyl sulfate showed enhanced antifungal activity against *Candida* albicans compared to conventional antifungal agents [52]. The antifungal activities depend on size of different AgNPs were execute beside mature "Candida albicans" and "Candida glabrata" biofilms. Biologically synthesized AgNPs exhibited antifungal activity against numerous phytopathogenic fungi, as well as *Alternaria alternata, Sclerotinia sclerotiorum, Macrophomina phaseolina, Rhizoctonia solani, Botrytis cinerea,* and *Curvularia lunata* at the concentration of fifteen mg [53-54]. Similarly, The AgNPs synthesized by Bacillus species exhibited strong antifungal activity against the plant pathogenic fungus Fusarium oxysporum at the concentration of 8 g/mL [55]. The antifungal effectiveness of AgNPs was estimated on combining with "nystatin" (NYT) or "chlorhexidine" (CHX) against Candida albicans and Candida glabrata biofilms. The results from this investigation suggest that AgNPs combined with either nystatin (NYT) or chlorhexidine digluconate (CHG) showed better synergistic anti-biofilm activity; however, the activity depends on the species and drug concentrations [56]. The bio-synthetic AgNPs reveal burly antifungal activity adjacent to "Bipolaris sorokiniana" by the inhibition of conidial germination [57]. Interestingly, AgNPs not only inhibit human and plant pathogenic fungi, but also effective against indoor fungal species such as *Penicillium brevicompactum, Aspergillus fumigatus, Cladosporium cladosporoides, Chaetomium globosum, Stachybotrys chartarum,* and *Mortierella alpine* cultured on agar media [58].

***Antiviral accomplishment-*** Viral mediated diseases are common and becoming more prominent worldwide; therefore, developing anti-viral agents is essential. The mechanisms of the antiviral activity of AgNPs are an important aspect in antiviral therapy. AgNPs have unique interactions with bacteria and viruses based on certain size ranges and shapes [27, 41, 59]. Due to the antiviral activity, nano-Ag incorporated into polysulfone ultrafiltration membranes; (nAg-PSf) was evaluated against MS2 bacteriophage, which shows the significant antiviral activity, due to increased membrane hydrophilicity [60]. AgNPs have demonstrated efficient inhibitory activities against human immunodeficiency virus (HIV) and hepatitis B virus (HBV) [61]. A study focused towards the antiviral action of the AgNPs; the information confirm that each scavenger cell (M)-tropic and T-lymphocyte (T)-tropic strains of HIV-1 were sensitive to the AgNP-coated polyurethane condom (PUC) [62]. Even though, numerous studies have revealed that AgNPs could slow down the viability of viruses nevertheless the exact mechanism of antiviral activity is still obscure. The studies by Trefry and Wooley found that AgNPs caused a four- to five-log reduction in infective agent titre at concentrations that weren't cytotoxic to cells [63]. Interestingly, in the presence of AgNPs, virus was capable of adsorbtion to cells, and this viral entry is responsible for the antiviral effects of AgNPs. The Hemagglutination assay indicated that AgNPs might considerably inhibit the growth of the influenza virus in Madin-Darby canine urinary organ cells i.e. kidney. The study as of intranasal AgNPs organization within mice considerably improved survival, lower lung viral titer levels, minor pathologic lesions in lung tissue, and remarkable survival advantage after infection with the $H_3N_2$ influenza virus, suggesting that AgNPs had a significant role in mice survival [64].

Biologically-synthesized AgNPs inhibited the viability of herpes simplex virus (HSV) types 1 and 2 and human para-influenza virus type 3, based on size and zeta potential of AgNPs [65]. The treatment of Vero cells with "non-cytotoxic" concentrations of AgNPs considerably repressed the replication of "Peste des petits ruminant's virus" (PPRV). The mechanisms of viral replication are due to the interaction of AgNPs with the virion surface and the virion core [66]. Tannic acid synthesized the assorted sizes AgNPs that is able to reduce "HSV-2" infectivity *in vitro* and *in vivo* through direct interaction, blocked virus attachment, penetration, and further spread [67]. The antiviral property of Ag+ alone or combination with 50 ppb Ag+ and 20 ppm $CO_3^{2-}$ (carbonate ions) was performed on bacteriophage MS2 phage. The results from this study evaluate that 50 ppb Ag+ alone was unable to affect the phage, and the combination of 50 ppb Ag+ and 20 ppm $CO_3$ was found to have an effective antiviral property within a contact time of 15 min [68].

***Anti-Inflammatory accomplishment-*** Inflammation is an early immunological response against foreign particles by tissue, which is supported by the enhanced production of pro-inflammatory cytokines, the activation of the immune system, and the release of prostaglandins and chemotactic substances such as complement factors, interleukin-1 (IL-1), TNF-α, and TGF-β [69-72]. To defeat inflammatory action, we should find efficient anti-inflammatory agents. Among several anti-inflammatory agents, AgNPs have recently played an important role in anti-inflammatory field. AgNPs have been known to be antimicrobial, but the anti-inflammatory responses of AgNPs are still limited [73] reported the anti-inflammatory activity in rat. The Rats treated intra-colonically with 4 mg/kg or orally with 40 mg/kg of nanocrystalline silver, showed significantly reduced colonic inflammation. The rata treated with AgNPs showed rapid healing and improved cosmetic appearance, occurring in a dose-dependent manner. Moreover, AgNPs demonstrate major antimicrobial properties, less wound inflammation, and modulation of fibrogenic cytokines [74]. Continuing the previous study, [70] investigated to gain further evidence for the anti-inflammatory properties of AgNPs, in which they used both *in vivo* and *in vitro* models and found that AgNPs are able to down-regulate the quantities of inflammatory markers, suggesting that AgNPs could suppress inflammatory events in the early phases of wound healing [70]. A porcine contact dermatitis model showed that treatment with nanosilver significantly increases apoptosis in the inflammatory cells and decreased the levels of pro-inflammatory cytokines [75]. Bio-synthetic AgNPs declines the production of cytokines that is induced by UV-B irradiation in HaCaT cells, and also reduces the edema and cytokine levels in the paw tissues [76].

***Anti-Angiogenic Activity-*** Pathological angiogenesis is a symbol of cancer and various ischemic and inflammatory diseases [77]. There are several research groups discovering novel pro- and anti-angiogenic molecules to overcome angiogenic-related diseases. Although there are several synthetic molecules having anti-angiogenic properties, the discovery of series of natural pro- and anti-angiogenic factors suggests that this may provide a more physiological approach to treat both classes of angiogenesis-dependent diseases in the future [78]. Recently, several studies provided supporting evidence by both *in vitro* and *in vivo* models showing that AgNPs have both anti-angiogenic and anti-cancer properties. Here, we summarize the important contribution in cancer and other angiogenic related diseases [79] confirmed the anti-angiogenic property of biologically synthesize AgNPs using bovine retinal endothelial cells (BRECs) as a model, where they found inhibition of proliferation and migration in BRECs after 24 h of treatment with AgNPs at 500 Nm concentration. The mechanisms of inhibition of vascular endothelial growth factor (VEGF) induced angiogenic process by the activation of caspase-3 and DNA fragmentation; and AgNPs inhibited the VEGF-induced PI3K/Akt pathway in BRECs [80]. Followed by "Gurunathan *et al.,*" concluded that the "anti-angiogenic" property of AgNPs along with "pigment epithelium derived factor" (PEDF) as a bench mark that is known to as a potent anti-angiogenic agent [81]. Using BRECs as a model system, they evaluate that AgNPs inhibited VEGF-induced angiogenic assays. Moreover, they established that AgNPs might obstruct the shape of new blood micro-vessels by the inactivation of PI3K/Akt. They also demonstrated the anticancer property of AgNPs using various cytotoxicity assays in Dalton's lymphoma ascites (DLA) cells, and a tumor mouse model showed significantly increased survival time in the presence of AgNPs [82]. AgNPs reduced with diaminopyridinyl (DAP)-derivatized heparin (HP) polysaccharides (DAPHP) inhibited basic fibroblast growth factor (FGF-2)-induced angiogenesis compared to glucose conjugation [80]. Kim et al. [83] developed an anti-angiogenic Flt1 peptide conjugated to tetra-N-butyl ammonium modified hyaluronate (HA-TBA), and it was used to encapsulate genistein [83]. By means of human umbilical vein endothelial cells (HUVECs), they found that genistein/Flt1 peptide-HA micelle inhibited the proliferation of HUVECs, and the same reagents could drastically reduce corneal neovascularization in silver nitrate-cauterized corneas of Sprague Dawley (SD) rats. The $Ag_2S$ quantum dots (QDs) used as nanoprobes to monitor lymphatic drainage and vascular networks. The $Ag_2S$-based nanoprobes showed long circulation time and high stability. In addition, they were able to track angiogenesis mediated by a tiny tumor (2-3 mm in diameter) *in vivo* condition [84]. Recently, *Achillea biebersteinii* flowers extract-mediated syntheses of AgNPs with concentration of 200g/mL express the 50% reduction in newly-formed vessels [85].

***Anticancer exploit-*** worldwide, ever third person has the possibility of cancer [86]. Although many chemotherapeutic agents are currently being used on different types of cancers however the side effects are enormous and particularly administrations of chemotherapeutic agents by intravenous infusion are a tedious process [86]. Therefore, it is indispensable to develop technologies to avoid systemic side effects. To overcome the issue, many researchers are developing nanomaterials as an alternative tool for formulations to target tumor cells specifically. Gopinath *et al.* [87] investigated the molecular mechanism of AgNPs and found that programmed cell death was concentration-dependent under conditions. Further, they observed a synergistic effect on apoptosis using uracil phosphoribosyl transferase (UPRT)-expressing cells and non-UPRT-expressing cells in the presence of fluorouracil (5-FU). Through the experimental conditions, they observed that AgNPs not only induce apoptosis but also sensitize cancer cells. The anticancer property of starch-coated AgNPs was studied in normal human lung fibroblast cells (IMR-90) and human glioblastoma cells (U251). AgNPs induced alterations in cell morphology, decreased cell viability as well as metabolic activity and increased oxidative stress leading to mitochondrial damage and increased production of reactive oxygen species (ROS), ending with DNA damage. Among these two cell types, U251 cells showed more sensitivity than IMR-90 [88]. The similar group also confirmed the cellular uptake of AgNPs mainly through endocytosis. AgNP-treated cells exhibited various abnormalities, including upregulation of metallothionein, downregulation of major actin binding protein, filamin, and mitotic arrest [88]. The morphology of cancer cells suggests that biologically synthesized AgNPs could induce cell death very significantly [89] elegantly prepared multifunctional silver-embedded magnetic nanoparticles, in which the first type consisting of silver-embedded magnetic NPs with a magnetic core of average size 18 nm and another type consist thick "silica shell" of silver with 16nm of average size; the consequential silica-encapsulated magnetic NPs (M-SERS dots) produce strong surface-enhanced Raman scattering (SERS) signals and have magnetic properties, and these two significant properties were used for targeting breast-cancer cells (SKBR3) and floating leukemia cells (SP2/O). The "antineoplastic activities" of "protein-conjugated silver sulfide nano-crystals" are dependent on size in human hepatocellular carcinoma Bel-7402 and C6 glioma cells [90]. Instead of giving direct treatment of AgNPs into the cells, some researchers developed chitosan as a carrier molecule for the delivery of silver to the cancer cells. For example, Sanpui *et al.* demonstrated that "chitosan-based nanocarrier" (NC) delivery of AgNPs induces apoptosis at extremely low concentrations [91]. They then examined cytotoxic efficiency using a battery of biochemical assays. They found an increased level of intracellular ROS in HT 29 cells. The Lower concentrations of nanocarrier with AgNPs showed better inhibitory results than AgNPs alone. Boca *et al.* [92] reported that "chitosan-coated silver nanotriangles" (Chit-AgNTs) point up growth in cell mortality rate. In addition, human embryonic cells (HEK) were able to take up Chit-AgNTs efficiently, and the cytotoxic effect of various sizes of AgNPs was significant in acute myeloid leukemia (AML) cells [93]. A moment ago, the anticancer assets of bacterial "B-AgNPs" and fungal extract-produced AgNPs "F-AgNPs" was demonstrated in human breast cancer MDA-MB-231 cells. Both biologically produced AgNPs exhibited significant cytotoxicity [94]. Among these, fungal extract-derived AgNPs had strong effect than B-AgNPs, owing to the type of reducing agents used for the synthesis of AgNPs. Similarly, AgNPs derived from Escherichia fergusoni showed dose-dependent cytotoxicity against MCF-7 cells [94]. The synthesis of AgNPs mediated by Plant extract validate more prominent toxic effect againsed human lung carcinoma cells (A549) than non-cancer cells like human lung cells, indicating that AgNPs could target cell-specific toxicity, which could be the lower level of pH in the cancer cells [95]. Targeted delivery is an essential process for the treatment of cancer. To address this issue, Locatelli *et al.* [96] developed multifunctional nanocomposites containing "polymeric nanoparticles (PNPs)", alisertib (Ali) and AgNPs. PNPs conjugated with a chlorotoxin (Ali@PNPs–Cltx) showed a nonlinear dose-effect relationship, whereas the toxicity of Ag/Ali@PNPs–Cltx remained stable. Bio-synthetic AgNPs validate significant toxicity in "MCF7" and "T47D" cancer cells by higher endocytic activity than MCF10-A normal breast cell line [97]. Banti and Hadjikakou explained the detailed account of anti-proliferative and anti-tumor activity of silver (I) compounds [98]. Bio-synthetic AgNPs are capable to alter cancer cell morphology, which is an early indicator for apoptosis. Apoptosis can be determined by structural alterations in cells by transmitted light microscopy.

***Textile Applications-*** The Nano materials are now commercially used in textile industries [99] by incorporating into fiber or coated with fiber, for instance Silver nanoparticles are used in T shirt, sporting clothes, undergarments, socks etc [100].

***UV rays blocking textile-*** "Inorganic UV blockers" are more advantageous over "organic UV blockers" as they are non-toxic and chemically stable on exposing to both high temperatures and UV [101-102]. Inorganic UV blockers are generally the semiconductor oxides that are $TiO_2$, ZnO, $SiO_2$ and $Al_2O_3$. Among these semiconductor oxides, titanium dioxide ($TiO_2$) and zinc oxide (ZnO) are commonly used. It was resolute that nano-sized "titanium dioxide" and "zinc oxide" are comparatively more efficient in absorbing and scattering UV radiation and provide better protection against UV rays. This is due to the fact that nano-particles have a larger surface area per unit mass and volume than the conventional materials, leading the increment ineffectively to block UV radiation [101, 103]. Many research puts forward for application of UV blocking treatment to fabric using nanotechnology. UV blocking treatment for cotton fabrics are developed by means of sol-gel method. For this, thin layer of titanium dioxide is formed on the surface of the treated cotton fabric which provides excellent UV protection; the effect can be maintained even after 50 home launderings [102]. Apart from titanium dioxide, zinc oxide nano rods of 10 to 50 nm in length are also applied to cotton fabric to provide UV protection. Previous studies on UV blocking effectively accomplished that the fabric treated with zinc oxide nanorods were found to have demonstrated an excellent UV protection factor (UPF) rating [104]. This effect can be further enhanced by means of various procedures for Appling the nanoparticles on the fabric surface. By applying padding process, nanoparticles, not only coated onto the surface of the fabric, but also penetrate into the interstices of the yarns and the fabric, i.e. some portion of the nanoparticles gets penetrated into the fabric structure. Such Nanoparticles that does not stay on the surface may not be very effective in shielding the UV rays.

It is worthwhile that only the right (face) side of the fabric gets exposed to the rays and therefore, this surface alone needs to be covered with the nanoparticles for better UV protection. Spraying (using compressed air and spray gun) the fabric surface with the nanoparticles can be an alternate method of applying the nanoparticles.

***Medicinal Textiles and Devices***- AgNPs synthesized using *A. dubius* fabricated on the cotton cloth and perspiration pad samples express high resistance towards *Corynebacterium*, a sweat microorganism [88]. The Antibacterial drug activity of gauze fabric discs incorporated with AgNPs, made from the inexperienced mature thalli of *Anthoceros* exhibit antimicrobial activity against *Pseudomonas aeruginosa* [89]. *Curcuma longa* tuber dust enveloped silver nanoparticles exhibited minimum bactericidal concentration (MBC) for *Escherichia coli* BL-21 strain at 50mg/L. The immobilization onto the fabric by means of sterile water is reported to specify higher antiseptic activity on compared with polyvinylidene fluoride immobilized cloth [90]. The incorporation of *Azadirachta indica* synthesized silver nanoparticles into cotton cloth results in antibacterial drug effect against *E. coli* [91].

***Significance of AgNPs in Food Industry-*** AgNPs is widely used in food industry reported by Cushen and co-workers [105] chiefly due to antibacterial activity and preservative free. Least amount of AgNPs is safe for human however deadly to, majority of viruses and bacteria, thus making them useful for sanitization of food and water in day to day lifestyle and an infection resistor in medicine. Sunriver industrial Nano silver fresh food bag is one of the commercially available bag in which silver nanoparticles are applied [106]. AgNPs are widely used in daily product that is soaps, food, plastics, pastes and textiles due to their anti-fungicidal and anti-bactericidal activities.

***Nanotechnology and food packaging-*** A desirable packaging material should have permeability to gas and moisture with strength and biodegradability [107]. Nano-based “smart” and “active” food packaging confers several advantages over conventional packaging methods for providing better packaging material with improved mechanical strength, barrier properties and antimicrobial films to nanosensing the pathogen detection and alerting the consumers for the safety status of food [108]. The nanocomposites “an active material” for packaging and material coating can also be used to improve food packaging [109]. Many researchers build awareness towards antimicrobial property [110-111] of organic compounds i.e. essential oils, organic acids, and bacteriocins [110-111] and their relevance in polymeric matrices as antimicrobial packaging. However, these compounds are not suitable for various food processing steps that require high temperatures and pressures because of high sensitivity to the physical conditions. By using inorganic nanoparticles, a strong antibacterial activity can be achieved in low concentrations and get more stable in extreme conditions. Therefore, recently it becomes interesting for using these nanoparticles in antimicrobial food packaging. The “antimicrobial packaging” is active packaging that contacts the food product or the headspace inside which inhibits or retards the microbial growth present on food surfaces [112]. Several nanoparticles such as silver, copper, chitosan, and metal oxide nanoparticles like titanium oxide or zinc oxide have been reported to have antibacterial property [113-114].

***Food processing-*** Some food processing techniques exploit enzymes to modify food components to improve their flavor, nutritional quality or other characteristics. The Nanoparticles used as a source to immobilize these enzymes, which may aid in the dispersion throughout the food matrices and enhance their activity. The “Nano-silicon dioxide” particles along with reactive aldehyde groups that are covalently bound [115] to a porcine triacylglycerol lipase effectively hydrolyze olive oil. They facilitate the improvement in stability, adaptability, and reusability [115]. Nanocharcoal adsorbent is a nanoparticle product used for the decoloration of food products [116].

**Environmental treatments**

***Air disinfection-*** The Bioaerosols are airborne particles of biological origins, including viruses, bacteria, fungi, which are capable of causing infectious, allergenic or toxigenic diseases. Particularly, indoor air bioaerosols were found to accumulate in large quantities on filters of heating, ventilating, and air-conditioning (HVAC) systems [117]. It is established that outdoor air pollution and insufficient hygiene of an HVAC installation often resulted in lower quality of indoor air. Moreover, the organic or inorganic materials deposited on the filter medium after air filtration contribute to microbial growth. The WHO estimated that 50% of the biological contamination present in indoor air comes from air-handling systems, and the formation of harmless micro-organisms such as bacterial and fungal pathogens was found in air filters. Most of these pathogens produce mycotoxins, which are dangerous to human health, thus microbial growth in air filters get reduced by the integrating antimicrobial Ag-NPs into the air filters. The antimicrobial effect of Ag-NPs on bacterial contamination of activated carbon filters (ACF) was studied by Yoon *et al.* [117]. The results showed that Ag-deposited "ACF filters" were effectively removes bioaerosols. The antibacterial activity analysis of Ag-coated "ACF filters" indicated that two bacteria of *"Bacillus subtilis"* and *E. coli* were completely inhibited within 10 and 60 min, respectively. It was found that silver deposition did not influence the physical properties of ACF filters such as pressure drop and filtration efficiency, however, the adsorptive efficacy was decreased by silver deposition. Hence, the authors moreover suggested that the quantity of Ag-NPs on the "ACF filters" needs to get optimized to avoid excessive reduction of their adsorptive characteristics and to show effective antimicrobial activity. Recently, Jung *et al.* [118] generated Ag-coated CNT hybrid nanoparticles (Ag/CNTs) using aerosol nebulization and thermal evaporation/condensation processes and considered their applicability to antimicrobial air filtration. CNT and Ag-NPs aerosols mixed together and attached to each other, forming Ag/CNTs. The antimicrobial activity of Ag/CNT-coated filters was tested against Gram-positive bacteria *S. epidermidis* and Gram-negative *E. coli*. It was found that when Ag/CNTs were deposited on the surface of an air filter medium, the antimicrobial activity against tested bacterial bioaerosols was enhanced, compared with the deposition of CNTs or Ag-NPs alone, whereas the filter pressure drop and bioaerosol filtration efficiency were similar to those of CNT deposition barely. It was reported that the surface area of Ag-NPs was enhanced by CNTs thus stands the main reason for the higher antimicrobial filtration efficacy of Ag/CNTs compared with that of pure Ag-NPs. Polymer air filters made of polypropylene and silver nitrate ($AgNO_3$) were examined for bacterial survival [119]. The study demonstrates that the addition of antibacterial $AgNO_3$ agent to filters was effective for preventing bacteria for colonizing filters. The presence of an antimicrobial $AgNO_3$ compound in the air filters decreases the amount of bacteria, which was observed in the case of both Gram-negative and Gram-positive bacterial strains of *Micrococcus luteus, Micrococcus roseus, B. subtilis,* and *Pseudomonas luteola*. The apparent reduction in bacterial cell growth on silver treated filters made the technology of antimicrobial filter treatment really necessary for the future.

**Water disinfection**

***Drinking water disinfection*-** Water is one of the most important substances on Earth and is essential to all living things. About 70% of the Earth is covered with water, but only 0.6% is suitable for human consumption. Safe drinking water is an important health and social issue in many developing countries [120]. According to the WHO, at least 1 billion people do not have access to safe drinking water. Contamination of drinking water and then the subsequent outbreak of waterborne diseases are the leading cause of death in many developing nations [121]. Moreover, the spectrum and the incidence of some infectious diseases are increasing worldwide, therefore, there is an enormous need for treatments to control the microbial contamination of water and decrease the number of waterborne diseases. Significant interest has arisen in using Ag-NPs for water disinfection. The chemicals produced nanosilver (chem-Ag-NPs) can be uniformly decorated onto porous ceramic materials to form an Ag-NPs–porous ceramic, composite by using 3-aminopropyltriethoxysilane (APTES) as a connecting molecule [122]. This composite can be stored for long periods and is durable under washing without loss of NPs. The sterilization property of Ag-NPs-porous ceramic, composite as an antibacterial water filter was tested with *E. coli*. It was found that at a flow rate of 0.01 l $min^{-1}$, the output count of *E. coli* was zero while input water had a bacterial load of 105 CFU $ml^{-1}$. It also confirms that the connection between the *chem*-Ag-NPs and the ceramic based on the coordination bonds between the -NH2 group at the top of the APTES molecule and the silver atoms on the surface of the NPs. This kind of connection ensured that the *chem*-Ag-NPs were tightly fixed to the interior channel walls of the porous ceramic so that they can release sufficient quantity of silver ions for antibiosis. Such Ag-NPs–porous ceramic composites were successfully tested in drinking water purification [123]. Additionally, the *chem*-Ag-NPs can be coated on common polyurethane (PU) foams by overnight exposure to *chem.* Ag-NPs colloid [124]. The NPs are stable on the foam and are not washed off with water and Morphology of the foam gets retained after coating. The NPs binding is due to its interaction with PU's nitrogen atom. On reaching flow rate of 0.5 l $min^{-1}$, after few seconds the output count of *E. coli* was nil while input water had a bacterial load of 105 $CFUml^{-1}$. The "*chem*-Ag-NPs" were also successfully formed on to the macroporous "methacrylic acid copolymer" beads for disinfection of water [125]. This showed that the *chem*-Ag-NPs formed on these copolymer beads by the chemical reduction method were stable underwater washing and their stability was due to the interaction of the "*chem*-Ag-NPs" to the "–COO−" carboxylic functional group on the "copolymer beads". Polymeric microspheres containing *chem*-Ag-NPs displayed highly effective disinfection against two gram-negative bacteria (*E. coli, P. aeruginosa*) and two gram-positive bacteria (*B. subtilis, S. aureus*) strains. The *chem*-Ag-NPs bound copolymer beads performed efficiently in bringing down the bacteria count to zero for all the tested strains. The bacterial adsorption or adhesion analysis revealed that "copolymer beads" containing "*chem*-Ag-NPs" do not have any adsorption/adhesion of bacterial cell.

***Groundwater and biological wastewater disinfection-*** The impact of Ag-NPs on microbial communities in wastewater treatment plants was evaluated [126] and found that original wastewater biofilms are highly tolerant to Ag-NP treatment. With an application of 200 $mg^{-1}$ Ag-NPs, the reduction of biofilm bacteria measured by heterotrophic plate counts was insignificant after 24 h. Biofilm can provide physical protection for bacteria under Ag-NP treatment, and extracellular polymeric substances (EPS) may play an important role in this protection. Susceptibility to Ag-NPs is different for every microorganism on the biofilm microbial community. The study illustrates two implications: (i) Ag-NPs could impact wastewater biofilm microbial community structures, depending on the characteristics of each strain, e.g., its ability to produce EPS and growth rate and the community interactions among these strains; and Mpenyana-monyatsi *et al.* [127], (ii) the effects of Ag-NPs on planktonic cells [127] were different to those on wastewater biofilms. Biofilm bacteria treated as isolated pure culture is much more sensitive to Ag-NPs, in contrast to the mixture of bacteria in the biofilm. A moment ago, novel, cost-effective filter materials that was coated with *chem*-Ag-NPs were developed for the disinfection of ground water [127], thus revealed that the *chem*-Ag-NPs were successfully deposited on zeolite, sand, fibre-glass, anion and cation resin substrates. The performance of these substrates as an antibacterial water filter system was tested for the removal of pathogenic bacteria of *E. coli, S. typhimurium, S. dysenteriae* and *V. cholera* in groundwater. The results exposed the maximum bacteria exclusion efficiency of the Ag/cation resin filter, with complete (100%) removal of all targeted bacteria, and the lowest by the Ag/zeolite filter, with an 8-67% removal rate.

**Pharmacological Applications**

***Antimicrobial activity-*** Silver nanoparticles synthesized using "*Abutilon indicum"* leaf [128] extract exhibited highly potent antibacterial activity agonized *Staphylococcus aureus* (16.8 mm), *Bacillus subtilis* (18.3 mm), *Salmonella typhi* (14.5 mm), and *Escherichia coli* (17.2 mm) [128]. The impregnation of *Ipomea carnea*-AgNPs with a cellulose acetate membrane, to form a structured antimycobacterial membrane show 14mm zone of inhibition on *Mycobacterium smegmatis* [129]. *"Boerhaavia diffusa"* mediated AgNPs express higher sensitivity against *"Flavobacterium branchiophilum"* [130] than the other two fish bacterial pathogens are *Aeromonas hydrophila* and *Pseudomonas fluorescens* [130]. Lingo-berry and cranberry juice assist AgNPs, found additional against *S. aureus*, *B. subtilis*, and *B. cereus* and fewer active against *C. albicans* and food borne *B. cereus* [131]. The development of *V. alginolyticus, K. pneumoniae, P. aeruginosa, B. subtilis,* and *P. shigelloides* was extremely inhibited by the AgNPs synthesized exploiting the inflorescence of the *Cocos nucifera*. The "Antidermatophytic activity" of AgNPs synthesized with lemon peel extract showed zone of inhibition [132] at 12 ± 0.3SD, 11 ± 0.5SD against *T. mentagrophytes* and *C. albicans*, respectively, however, no activity noticed against *T. rubrum* [132]. Triangular, hexagonal, and spherical AgNPs of 78nm and 98 nm in size, formed by the leaf extracts of *Caesalpinia coriaria* showed higher bactericide activity against *E. coli*

(12 mm) and *Pseudomonas aeruginosa* (18 mm) [133]. Apoptosis of *C. albicans* and *S. cerevisiae* by *P. oleracea*-mediated AgNPs is due to generation of reactive oxygen species and decreased production of hydroxyl radicals initiated by the phytoconstituents capped on the synthesized AgNPs [134]. *In vivo* analysis of biochemical and microscopic anatomy provides evidence regarding bactericide impact of AgNPs synthesized using *Leucas aspera* on fish models (*Aeromonas hydrophila* and *Catla catla*) [135]. The Antimicrobial activity of *Sphaeranthus amaranthoides* extract synthesized silver nanoparticles Schlinkert *et al.* [136] was reported to be amplified because of the destabilization of the outer membrane, blocking bacterial respiration, and depletion of intracellular ATP leads to the denaturation of microorganism cell wall. AgNPs synthesized using *Vinca rosea* leaf extract showed [136] promising inhibition against *Staphylococcus aureus*, *Lactobacillus*, *Escherichia coli*, and *Pseudomonas fluorescens* at 10 $\mu$L concentrations [136]. *Mukia scabrella* synthesized AgNPs showed 81.81%, 90%, and 63.23% antibacterial activity against nosocomial Gram negative bacterial pathogens *Pseudomonas aeruginosa, Klebsiella pneumoniae,* and *Acinetobacter,* respectively [137]. The highest zone of inhibition (16mm) was obtained for the AgNPs synthesized using *"Citrus sinensis*" [40] and *Centella asiatica* against *Pseudomonas aeruginosa* compared to that of AgNPs produced using *Syzygium cumini* and *Solanum trilobatum* [40]. *Datura alba* (Nees) leaf derived silver nanoparticles showed better inhibitory zone (20 mm) against *Clostridium diphtheriae* and cell death is accounted and accompanied by the protein denaturation and rupturing of bacterial cell wall [43]. The AgNPs synthesized using a extract of methanol from "*Solanum xanthocarpum"* berry signify a stronger "anti-*H. pylori"* [25] activity and a noncompetitive inhibition were concluded from Lineweaver-Burk plots [25]. *Desmodium triflorum* extract aided AgNPs inhibited the growth of *Staphylococcus* and *E. coli* by 62 and 88%, respectively, at 14–60 $\mu$g/cm3 concentrations after 24 hours, while 100 $\mu g/cm^3$ concentration showed approximately 100% inhibition [44]. *Gelidiella acerosa* extract synthesized AgNPs are highly active against tested fungal species at a 50 $\mu$L concentration against *Mucor indicus* (22.3 mm) and *Trichoderma reesei* (17.2 mm) compared to the standard antifungal agent Clotrimazole [45]. Maximum inhibitory zones (25 and 27mm) were noted for *Ocimumsanctum* leaf extract aided AgNPs against *Proteus vulgaris* and *Vibrio cholerae*, respectively. The leaf extract having nanoparticles of *Vitex negundo* showed a minimum inhibition rate against the aforementioned bacterial pathogens [46]. Silver nanoparticles using leaf broth of *Gliricidia sepium* at 50 $\mu$L concentrations showed 3mm zone of inhibition [47] for *Staphylococcus aureus* and 2mm for *Escherichia coli*, *Pseudomonas aeruginosa*, and *Klebsiella pneumonia* [47].

***Larvicidal Activity-*** The larvicidal activity of *Leucas aspera* aided synthesized AgNPs demonstrate the maximum efficacy at LC50 values of 8.5632, 10.0361, 14.4689, 13.4579, 17.4108, and 27.4936 mg/L and LC90 values of 21.5685, 93.03928, 39.6485, 42.2029, 31.3009, and 53.2576mg/L, [48] respectively, against the fourth instar larvae of *A. aegypti* [48]. AgNPs synthesized with *Drypetes roxburghii* (Wall.) express 100% mortality in second instar larvae of *Anopheles stephensi* at 5 ppm concentration and 100% mortality in all instars of *Culex quinquefasciatus* and *Anopheles stephensi*, respectively, at double the concentrations [138]. AgNPs of size 25-30 nm synthesized using an aqueous leaf extract of *Nerium oleander* showed highest mortality against both larvae and pupae of *Anopheles stephensi* [139]. The exposure of the larvae to assorted concentrations of *Pedilanthus tithymaloides*-AgNPs [140] showed 100% mortality from first to fourth instars and pupae of *A. aegypti* after 24 h. Lethal concentration (LC50) values of AgNPs were found to be 0.029, 0.027, 0.047, 0.086, and 0.018% against the larval and pupal stages, with no mortality with "control" [140]. Synthesized AgNPs using *Sida acuta* are reported to have significant activity against the vector mosquito's *A. stephensi*, *A. aegypti*, and *C. quinquefasciatus*, respectively [141]. The IC50 values for the "antiplasmodial activity" of the AgNPs synthesized using "aqueous extracts" [142] of Ashoka and Neem leaves against *Plasmodium falciparum* are 8 and 30 $\mu$g/ml respectively [142]. *Vinca rosea* synthesized AgNPs does not exhibit any conspicuous toxicity on *Poecilia reticulata* after 24, 48, and 72h of exposure, but are reported to possess the potential to control *A. stephensi* and *C. quinquefasciatus* [143]. *"Euphorbia hirta"* synthesized AgNPs showed highest larval mortality values of LC50 against larvae and pupae [144]. The adulticidal and larvicidal activity of synthesized

AgNPs of *C. quadrangularis* represent 100% mortality against *H. maculate* and *R.(B.) microplus* [30]. The Appreciable larvicidal activity of synthesized AgNPs by utilizing the aqueous extract of *Eclipta prostrata* is reported against *Anopheles subpictus* and *Culex tritaeniorhynchus* [49].

***Wound healing property-*** Silver nanoparticles synthesized within the network of peptide fibers using ultraviolet irradiation repressed the microorganism growth of *E. coli, P. aeruginosa*, and *S. aureus*. AgNPs containing hydrogels on HDFa cells didn't show any vital influence on cell viability [145]. "AgNPs hydrogel" derived from *"Arnebia nobilis"* root extract examined for wound healing action in an excision [69] animal model exert a positive result attributed to their antimicrobial potential and provided a novel therapeutic direction for wound treatment in clinical observe [69]. *"Indigofera aspalathoides"* mediated AgNPs were eamined for wound-healing applications following excision in animal models [70]. AgNPs derived from *Chrysanthemum morifolium* added to clinical ultrasound gel and used on an ultrasound probe were found to exhibit antiseptic activity contributive to the sterility of the instrument [71]. *In vitro* study of the AgNPs-based dressing, Acticoat Flex three applied to a 3D embryonic cell culture [72] and partial thickness burns patient showed that AgNPs greatly reduce mitochondrial activity and cellular staining techniques revealed nuclear integrity with no signs of death [72]. AgNPs drive the differentiation of fibroblasts into myofibroblasts and promote wound contraction, thereby increasing the wound healing effectiveness [73]. The reduction in wound inflammation with modulation in the liver and urinary organ functions was observed throughout skin wound healing by the positive effects of silver nanoparticles through their antimicrobial properties [74]. AgNPs play a responsibility in dermal contraction and epidermal reepithelialisation during wound healing; contribute to the increased rate of wound closure [75]. AgNPs prepared extracellularly using the fungus *Aspergillus niger* are reported to modulate cytokines involved in wound healing within the excision rat model [76]. A considerable reduction in wound-healing was observed in a median time of 3.35 days for the AgNPs incorporated onto the cotton cloth and dressings and microorganism clearance was also improved from infected wounds devoid of adverse effects [77-80, 83, 85-87]. Silver nanoparticles exert antimicrobial properties inflicting reduction in wound inflammation and modulation of fibrogenic cytokines [146].

**Miscellaneous Applications**

*Manilkara zapota* leaf extract mediates the synthesis of AgNPs and showed a caricidal activity at LC50 3.44mg/L against *Rhipicephalus* (Boophilus) *microplus* (Rajakumar and Rahuman, 2012) [147]. AgNPs synthesized using *Jatropha gossypifolia* plant extract showed higher amoebicidal activity against *Acanthamoeba castellanii* trophozoites [148]. The nonlinear refraction and absorption coefficient values of AgNPs synthesized using *Coriandrum sativum* extract measured by Z-scan technique with ns laser pulses showed superior optical nonlinearity compared to those synthesized through other procedures [149].

***Water treatment-*** Stable AgNPs synthesized using *Anacardium occidentale* fresh leaf extract at 80$^o$C bud as a novel probe for sensing chromiumions [Cr (VI)] in tap water [150]. The population of bacteria decreased once the concentration of silver nanoparticles prepared using 10mg leaf extract (*Prosopis juliflora*) was treated with 100mL of waste material after 6 h and will increase because the time of incubation increases [151].

***Catalytic activity-*** The size dependent, catalytic activity of the synthesized AgNPs using Kashayam, Guggulutiktham, was established in the reduction of Methylene Blue (MB) by $NaBH_4$ [152]. *Acacia nilotica* pod mediated silver nanoparticles changed glassy carbon conductor express larger catalytic activity on the reduction of benzyl chloride compared to those of glassy carbon and metallic Ag electrode [153]. Photocatalytic degradation of methyl orange was measured spectrophotometrically using *Ulva lactuca and* synthesized AgNPs as nanocatalyst under visible light illumination [154]. The manufactured AgNPs using *Gloriosa superba* plant extract act through the electron relay effect and influence the degradation of methylene blue at the end of the 30 min [155]. Hydrogen peroxide reduces quickly with the outstanding catalytic activity of polydispersed silver nanoparticles synthesized via *Triticum aestivum* (khapali ghahu) extract [156]. The reduction of 4-nitrophenol (4-NP) into

4-aminophenol (4-AP) carried out with the *Breynia rhamnoides*-AgNPs having NaBH4 and establish to be depend on the nanoparticle size or the stem extract concentration [157].

## CONCLUSION

The review encompasses various applications of the silver nanoparticles in numerous sectors. New insights about the pharmacological applications such as anticancer, larvicidal, medical textiles, and devices are gleaned with these exotic silver nanoparticles. Hence, these biogenically synthesized silver nanoparticles can lead a major payoff in the field of bio-nanomedicine. Nanotechnology represents a modern and innovative approach to develop and test new formulations based on metallic nanoparticles with antimicrobial properties. Silver nanoparticles represent a prominent nanoproduct with potential application in medicine and hygiene. Characteristics of silver nanoparticles such as shape and size are important not only for augmenting the antimicrobial activity, but also for reducing tissue and eukaryotic cell toxicities. The possible risks to human health posed by silver nanoparticles and increased entry into the environment, with subsequent spread of microbial resistance, are of increasing concern given the rise of silver-containing products on the market.

## FUTURE PROSPECTS

It is important to note that despite of decay uses, the evidence of toxicity of silver is still not clear. With observed advantages such as long-lasting effect and enhanced bactericidal activity, the Ag-NPs are promising for environmental treatments contaminated with gastrointestinal bacteria and other infectious pathogens. More significantly, the powerful disinfectant activity of Ag-NPs can open a brand new generation of silver-containing disinfection products for controlling and preventing further outbreak of diseases (e.g. biofilm, diarrhea, and cholera). However, the emerging questions on the disinfectant ability of Ag-NPs against viral infections (e.g. Rota virus, A-H5N1 influenza virus, Enterovirus 71, etc.) need more clarification. Further analysis of disinfectant potency by silver-based NPs for real environmental contaminations are more demanding. Research in the field of Ag-modified textile fibers will be conducted in different directions: in-situ synthesis of AgNPs in textile fibers with the use of environment friendly chemicals, pretreatment of textile fibers to increase the adsorption of AgNPs and to stabilize their embedment in the fibers as well as to control the release of AgNPs from the fiber surfaces, improvement of the mode of Ag application to preserve the washing fastness of the coating, development of new application processes to achieve multifunctional textile fibers with antimicrobial properties, investigation regarding impact of Ag-modified textile fibers on human health and the environment.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this review article.

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