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Review on synthesis, characterization and applications of silver nanoparticles

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Abstract- From past few decades drug delivery using particulate delivery systems as carriers for small and large molecules is considered remarkably. Nano-crystalline silver particles has applications in the fields of high sensitivity biomolecular detection, antimicrobials, diagnostics, catalysis, therapeutics, and micro-electronics. Silver is well known from ancient time for inhibitory effect toward many bacterial and fungal strains and microorganisms commonly present in medical and industrial processes.

This review will focus on the key properties of silver nanoparticles, their method of preparation, and its application in medicine, diagnostics and pharmaceutical industry. It concludes that due to unique physicochemical properties of metal nanoparticles like catalytic activity, optical properties, electronic properties, antibacterial properties and magnetic properties they have emerging applications in industries for preparation of consumer products and highly accepted application in biomedical fields (specifically antimicrobial, antifungal, anti-inflammatory effects, and wound healing ability).

Index Terms:- Silver Nanoparticle, Antimicrobial, Chemical Reduction.

I. Introduction-

Silver is a soft, white, lustrous transition metal possessing unique properties like high electrical and thermal conductivity. These special characteristics of silver nanoparticles used in different fields viz. antimicrobial, antifungal, anticancer, larvicidal, catalytic, and wound healing activities. Silver nanoparticles are used in many forms as coins, vessels, solutions, foils, sutures, and colloids as lotions, ointments, and so forth[1,17].

To fulfill the requirement of silver nanoparticles, various methods have been adopted for synthesis. Biologically-prepared silver nanoparticles show high yield, solubility, and high stability [34]. In physical methods of synthesis, the silver nanoparticles can be generally synthesized by evaporation–condensation, which is carried out in tube furnace at atmospheric pressure. Silver nanoparticles are synthesized by gamma irradiation technique, electron irradiation mechanism and laser ablation to obtain in various sizes and shapes [2].

The photo-induced synthetic mechanism involves two distinct approaches, viz. photophysical (also known as top down) and photochemical (bottom up) ones. The advantages of the photochemical synthesis are: (i) it provides properties for photo-induced processing, like clean process, convenience of use and high spatial resolution.(ii) it has great versatility; it enables one to fabricate the nanoparticles in various mediums like emulsion, surfactant micelles, polymer films, glasses, cells, etc[3,18,19].

Biosynthesis of the nanoparticles has attention due to the growing need to develop technologies which are not harmful to environment in material synthesis. Microorganisms like bacteria, algae, yeast, and fungi can be used for intra and extracellular synthesis of metal nanoparticles, the use of parts of the whole plant in analogous with nanoparticles synthesis method is an exciting possibility which can be newly explored. In number of literatures, number of bacterial strains such as Pseudomonas aeruginosa, Acinetobacter calcoaceticus, Escherichia coli were used effectively for the formulation of silver nanoparticles. The benefits of using plants for the synthesis of the silver nanoparticles are that the plants can be very easily available and possess a large variety of active functional groups that can promote the reduction of silver ions(4).

Generally, the chemical method for synthesis involved following heads: (i) metal precursors, (ii) reducing agents (iii) stabilizing/capping agents. In general the reduction of silver salts involves following stages-

1) Nucleation
2) Subsequent growth.

Generally, silver nanomaterials can be obtained by two methods, as "top-down" and "bottom-up". The "top-down" method involves mechanical grinding of bulk metals and its stabilization using protecting agents. The "bottom-up" methods deals with chemical reduction, Sono-decomposition electrochemical method (5).

The physicochemical properties of nanoparticles are essential for their behavior, safety, efficacy and bio-distribution. So that, characterization of silver nanoparticles is necessary in order to evaluate the functional aspects of the synthesized nanoparticles. Characterization is performed using a various analytical techniques, including UV-vis spectroscopy, X-ray diffractometry (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)(5).

Figure 1: Applications of silver nanoparticles

II. Synthesis of silver nanoparticles-

Table No 1: Synthesis methods of silver nanoparticle

Type of synthesis	Silver precursor	Reducing agent or solvent	Stabilizer
Physical Synthesis	$AgNO_3$	Thermal decomposition, AC power, Electrical arc discharge, Glycerol and water	Sodium oleate, Silica, Sodium citrate
Chemical Synthesis	$AgNO_3$	Trisodium citrate, Ethylene glycol, $NaBH_4$, Ethylene glycol, Paraffin	Trisodium citrate, PVP(Poly-vinyl pyrrolidone), Dodecanoic acid, Oleyl amine.
Photochemical Synthesis	$AgNO_3$	Carboxymethylated chitosan, UV sodium citrate, Light sources, UV	TX-100, CMCTS, Sodium citrate, PVP.
Biological Synthesis	$AgNO_3$	Peptide, Bacillus sp. Lactobacillus, Fungus *T. viride* Cassia angustifolia	Peptide, Bacillus sp., Proteins, Cassia angustifolia

Physical method of synthesis-

In physical synthesis, metal nanoparticles are synthesized by evaporation condensation, which could be carried out using a tube furnace at atmospheric pressure. The source material is centered at the tube furnace and is vaporized into a carrier gas. However, the generation of silver nanoparticles using a tube furnace has several drawbacks, because a tube furnace requires large space and requires the higher energy so that the environmental temperature around the source material is increased, and requires a lot of time to achieve thermal stability. A typical tube furnace requires power consumption of more than several kilowatts and a preheating time of 10 minutes to attain a stable operating temperature. Furthermore, silver nanoparticles have been synthesized with laser ablation of metallic bulk materials in solution.[(6,20)]

Furthermore, silver nanoparticles are also synthesized with laser ablation of metallic bulk materials in solution. One advantage of laser ablation over other conventional method for preparing metal colloids is the absence of chemical reagents in solutions. Therefore, pure colloids, which will be useful for further applications, can be produced by this method.[(7,21)]

In summary, the physical synthesis of silver nanoparticles usually utilizes the physical energies to produce silver nanoparticles with nearly narrow size distribution.[(6,20)]

CHEMICAL METHOD OF SYNTHESIS-

The size, shape, and surface characteristics play an important role in controlling the chemical, physical, optical, and electronic properties of nanomaterials. The chemical reduction is the most commonly used method for the formulation of silver nanoparticles by inorganic and organic reducing agents. In general, various reducing agents such as sodium citrate, ascorbate, sodium borohydride (NaBH4), elemental hydrogen, polyol process, Tollens reagent, N,N-dimethylformamide (DMF), and poly(ethylene glycol)-block copolymers, hydrazine, and ammonium formate are used for the reduction of the silver ions (Ag+) in the aqueous or nonaqueous solutions.

Different shapes of silver nanoparticles synthesized by using various chemical reductants-

- **Synthesis of spherical silver nanoparticles**

The spherical silver nanoparticles can be synthesized using the reducing agents such as ascorbic acid, sodium citrate, NaBH4, thiosulfate, and polyethylene glycol. In addition to that, the use of the surfactants such as citrate, poly vinyl pyrrolidone (PVP), cetyltrimethylammonium bromide (CTAB), and polyvinyl alcohol (PVA) for interactions with particle surfaces can stabilize particle growth and protect particles sedimentation and particle agglomeration.[4]

- **Synthesis of silver nanorods**

At first step, monodisperse spherical seed nanoparticles are prepared by irradiating silver nitrate, bis(p-sulfonate-o-phenyl)-phenyl phosphine dihydrate dipotassium salt (BSPP), trisodium citrate, and sodium hydroxide solutions with 254 nm light. Then, Silver nanorods can be grown in the solution with the injection of silver seeds at the growth medium containing silver nitrate and sodium citrate and then irradiated for 24 h using a halogen lamp and a bandpass filter to selectively tune. This photo mediated method provided an elegant method for controlling the architectural parameters of the resulting silver nanostructures. [4,22]

- **Synthesis of cubic silver nanoparticles**

Cubic silver nanoparticles can be synthesized by the reduction of silver nitrate using ethylene glycol in the presence of polyvinylpyrrolidone (PVP). In polyol process, ethylene glycol has functional structure as both solvent and reducing agent. Cubic shape is constituted by using capping agent i.e. Polyvinyl-pyrrolidone. The shape of the product is determined by the molar ratio of the PVP and silver ions. The reduction agent is important for the synthesis of NPs with different chemical compositions, sizes and morphologies, and controlled disparities. [4, 23]

PHOTOCHEMICAL SYNTHESIS OF SILVER NANOPARTICLES-

The photochemical synthetic strategies can be categorized into two different techniques, that is the photophysical (top down) and photochemical (bottom up). In photophysical method silver nanoparticles are prepared via subdivision of bulk metals and the in photochemical method silver nanoparticle can be prepared from ionic precursors. The nanoparticles are synthesized by direct photoreduction of a metal source using photo-chemically generated intermediates (excited molecules and radicals) which is also known as photosensitization in the formulation of silver nanoparticles. Different light sources (UV, white, blue, cyan, green and orange) are used for direct photo-reduction process of AgNO3 in the presence of sodium citrate at room temperature. This light-modification process results in a colloid which have distinctive optical properties which can be related to the size and shape of the particles.

Another simple and reproducible UV photo-activation method for the preparation of stable Ag-NPs in aqueous Triton X-100 (TX-100) was reported. The TX-100 molecules act as a reducing agent and also nanoparticles stabilizer through template/capping action. Surfactant solution decreases the diffusion or mass transfer co-efficient of the system which helps to carry out the process of nanoparticle growth in diffusion controlled way and also increase the surface tension at the solvent-nanoparticle interface to improve the NPs size distributions.

Silver nanoparticles are also can be synthesized in an alkalic aqueous solution of AgNO3/carboxymethylated chitosan (CMCTS) with UV light irradiation. CMCTS (water-soluble and biocompatible chitosan derivative) used as reducing agent for silver cation and as well as stabilizing agent for silver nanoparticles in this method.

The main advantages of the photochemical synthesis are summarized as follows:

(i) It provides the advantageous properties the photo-induced processing, which is, clean process, high spatial resolution, and convenient for use.

(ii) The controlled in situ generation of reducing agents the formation of NPs can be triggered by the photo irradiation.

(iii) It has wide versatility the photochemical synthesis allows one to formulate the nanoparticles in different mediums including emulsion, surfactant micelles, polymer films, glasses, cells, etc.[3,24]

BIOLOGICAL SYNTHESIS-

- **Bacterial Induced Synthesis-**

The growth of P. aeruginosa is suppressed by Lactobacillus fermentum and it controls the formation of biofilm in the synthesis of biogenic silver nanoparticles. Spherical and triangular anisotropic nanoparticles synthesized by Bacillus flexus. For the synthesis of silver nanoparticles using Bacillus cereus 3-5 days of incubation period is required. The physical parameters (size and shape) of the silver nanoparticles prepared using microbes depend on the interaction of silver ions and bacteria.

- **Fungal derived synthesis-**

Cell free filtrate of *Helminthosporium tetramera* is used to synthesize the poly-dispersed spherical silver nanoparticles size ranged within 17-33nm. Ideal conditions such as temperature 37^0 C, pH 6.0, and substrate concentration of 2.0 mM silver nitrate are required to synthesize silver nanoparticles from *Aspergillus niger.* Silver nanoparticles synthesized by using *Pleurotus Sajor caju* have good antibacterial action against Pseudomonas aeruginosa and E. coli as compared to staphylococcus aureus. *Fasarium semitectum* fungus treated with aqueous silver nitrate solution will produce the highly stable and crystalline silver nanoparticles.

The reduction of silver ions takes place by the enzymes present on the surface of Verticillium and even after the formation of silver nanoparticles the cells were found to multiply. Thus the microbially assisted synthesis of silver nanoparticles are same as plant species. The enzymes present in the micro-organisms are responsible for the reduction of silver ions forming silver nanoparticles. These organisms are susceptible to higher concentrations of silver ions. Hence, the nano-silver synthesized by using micro-organisms exhibit certain difficulties when used in biomedical applications.

III. CHARACTERIZATION OF SILVER NANOPARTICLES-

The physicochemical properties of nanoparticles can define their behavior, bio-distribution, safety, and efficacy. So that the characterization of silver nanoparticles is important in order to evaluate the functional aspects of the synthesized nanoparticles. Various analytical techniques used for characterization of nanoparticles includes UV-vis spectroscopy, X-ray diffractometry (XRD), Fourier transform infrared spectroscopy (FTIR), dynamic light scattering (DLS), scanning electron on microscopy (SEM), transmission electron microscopy (TEM), and atomic force microscopy (AFM), X-ray photoelectron spectroscopy.[(5)]

UV-Visible Spectroscopy- Primary characterization of synthesized nanoparticles can be done by the UV-vis spectroscopy which is also used to monitor the synthesis and stability of silver nanoparticles. Silver nanoparticles have unique optic al properties which make them strongly interact with specific wavelengths of light. UV-vis spectroscopy is fast, easy, simple, sensitive, selective for different nanoparticles, needs only a short period time for analysis, and also calibration is not required for colloidal suspensions particle characterization. In silver nanoparticles, the two bands i.e. valence band and conduction band lie very close to each other in which electrons move freely. These free electrons lead to a surface plasmon resonance (SPR) absorption band, which occurs because of the collective oscillation of electrons of silver nano particles in the resonance with the light wave. The absorption of silver nanoparticles can vary on the particle size, dielectric medium, and chemical surroundings. The stability of silver nanoparticles prepared from biological methods was observed for more than 12 months, and an SPR peak at the same wavelength using UV-vis spectroscopy was observed. [(5)]

The SPR band characteristics of Ag NPs can be detected around 412–437 nm, which strongly suggests that the Ag NPs were spherical; this can be confirmed by the TEM results.[(9,25)]

X-ray Diffraction (XRD)- X-ray diffraction (XRD) is a most useful analytical technique which has been used for the analysis molecular and crystal structures, qualitative identification of diverse compounds, quantitative determination of chemical species, measure the degree of crystallinity, isomorphous substitutions, particle sizes, etc. X-ray patterns revealed the information about the physicochemical properties of the crystal, When X- ray beam reflects from the crystal surface.

In a powder sample, diffracted beams typically reflect its structural physicochemical character. Thus, XRD can revealed the structural units of a broad range of materials, like inorganic catalysts, superconductors, biomolecules, glasses, polymers, etc. Analysis of these leads to formation of diffraction patterns. Each material gives its specific diffraction beam/pattern which compared with diffracted beams with the reference database in the Joint Committee on Powder Diffraction Standards (JCPDS) library. The diffracted patterns also show purity and impurities present in sample. Therefore, XRD has long been used to define and identify both bulk and nanoparticles, forensic sample, industrial, and geochemical specimen materials. XRD is a prime technique for the identification of the crystalline properties at the atomic level. X-ray powder diffraction is a destructive method with great potential for the characterization of both organic and inorganic crystalline compound. This technique has been used to determine phase identification, conduct quantitative analysis, and to determine structure defect in samples from various control, such as geological, polymer, environmental, pharmaceutical, and forensic sciences. Recently, the applications have extended to the characterization of various nano-materials and their characteristics. The working theory of X-ray diffraction is Bragg's law. Typically, XRD is based on the broad-angle elastic scattering of X-rays. It has some drawbacks such as difficulty in crystal growth and the ability to get results pertaining only to single conformation/binding state. Another drawback of XRD is the low intensity of diffracted X-rays compared to electron diffraction.[5, 26]

Infrared spectroscopy-

For nanomaterial applications, FTIR (Fourier transform infrared spectroscopy is commonly employed to use the expression of characteristic spectral bands to reveal nanomaterial biomolecule conjugation i.e. to illustrate the conformational states of the bound protein. A new technique called Attenuated Total Internal Reflection in conjugation with IR spectroscopy to probe the structure of adsorbed/deposited species at a solid/air or solid/liquid interface, while avoiding the drawbacks of sample preparation complexity and spectral irreproducibility in conventional IR.[10]

Scanning Electron Microscopy-

SEM is the surface imaging method in which the incident electron beam scans across the sample surface and interacts with sample to generate signals reflecting the atomic composition and topographic details of specimen surface. The incident electrons cause emission of elastic scattering of electrons, referring to backscattered electrons, inelastic scattering of electrons named low energy secondary electrons, and characteristic X-ray light called cathodoluminescence from the atoms on the sample surface or near surface material. Among these emissions, detection of the secondary electrons is the most common mode in SEM and can achieve resolution smaller than 1 nm.[11, 27]

Transmission Electron Microscopy-

TEM is important technique used for the characterization of nanomaterials to obtain quantitative measures of particle and/ or grain size, size distribution, and morphology. The magnification of TEM is determined by the ratio of distance between the objective lens and specimen and distance between objective lens and its image plane.

Advantages of TEM-

- It can provide better spatial resolution.
- Capability for additional analytical measurements.

Disadvantages of TEM-

- It requires high vacuum, thin sample section and time consuming.

Atomic Force Microscopy-

AFM is useful to observed the dispersion and aggregation of nanoparticles, in addition to their size, shape and structure by three different scanning methods are available currently, like contact mode, non-contact mode, and intermittent sample contact mode. AFM can also use to distinguish the interaction of nanoparticles with lipid bilayers in real time, which is not easy to achieve with electron microscopy (EM) method. In addition, it can analyse up to the nano range in aqueous media. Although, a crucial disadvantage is the overestimation of the lateral dimensions of the samples due to the size of the cantilever. Therefore, we have to provide much focused to avoid wrong result prediction. Furthermore, the choice of operating mode—no contact or contact—is an important element in batch analysis.[5,11]

IV. MECHANISM OF SILVER NANOPARTICLES ON MICROBIAL CELL-

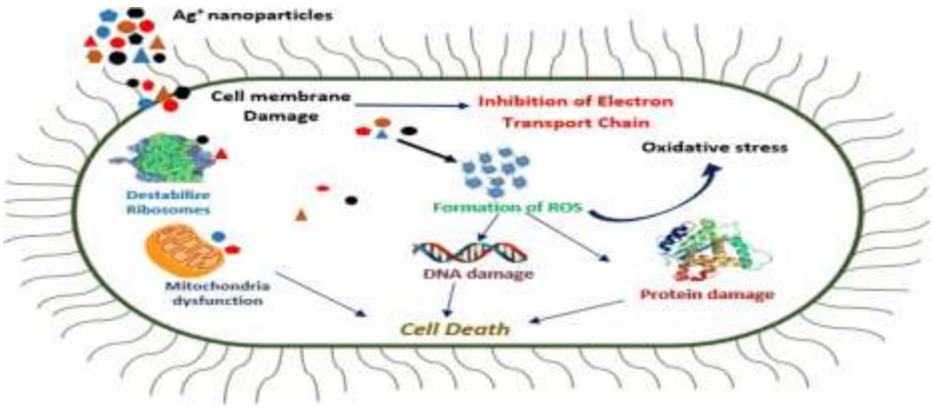

Figure No. 2 :- Mechanism of silver nanoparticles on microbial cell[39].

V. APPLICATIONS OF SILVER NANOPARTICLES-

Biomedical applications of silver nanoparticles in various sectors as follows-

1. Immunomodulatory effects of silver nanoparticles-

Silver nanoparticle manufacturers, particularly who are producing solutions of colloidal NPs, claim that Silver nanoparticles enhance immunity toward infections, potential immunomodulatory effects of silver nanoparticles are unknown. Among scientific community, there is no consensus regarding which immunology / molecular biology test should be used as the gold standard for evaluation of immunotoxicity of nanomaterials. Some traditional tests such as T-dependent antibody response (TDAR) assay which were in the past relatively popular for assessment of xenobiotic immunotoxicity, are today rarely used compared to ELISA and other similar protocols. And another mechanism is due to the small size of Silver nanoparticles and their proposed, but not yet completely understood ability to pass through membranes, it is possible that during the interaction with immune cells, they may bypass some conventional signal pathways reserved for larger molecules. Furthermore, silver nanoparticles can dramatically vary in size and shape, and data obtained for one Silver nanoparticles type do not necessarily imply that similar effects are caused by all Silver nanoparticles. Particularly interesting are the potential interactions between silver nanoparticles and peripheral blood mononuclear cells (PBMCs). It has been suggested that Silver nanoparticles may modulate interleukin 6 secretion mediated by Toll-like receptor (TLR) signaling in macrophages. Interleukin 6 is known as both pro-inflammatory and anti-inflammatory cytokine and regulation of its secretion is of major importance during infection and wound healing. Another study on has discovered that monocytes may increase release of interleukin 1 as the result of Silver nanoparticles exposure. Apart from its role in inflammatory response, interleukin 1 influences lymphocyte proliferation and maturation. If these Silver nanoparticles effects are confirmed in the future, it could open new possibilities in design of modern immunomodulatory medications as well as experimental models for laboratory research.[12,28]

2. Antibacterial activity-

Silver nanoparticles emerge as a substitute of antibacterial agent and have the ability to overcome the bacterial resistance against antibiotics. Among various promising nanomaterials, silver nanoparticles appear as a potential medication negotiator because of their massive surface-to-volume ratios and crystallographic surface structure. The antibacterial activity of silver nanoparticles is not only the size, but also shape dependent. Silver nanoparticles synthesized by four different types of saccharides with an average size of 25 nm, shows high antimicrobial and bactericidal activity against Gram-positive and Gram-negative bacteria, counting highly multi-resistant strains such as methicillin-resistant Staphylococcus aureus. The mechanism of Silver nanoparticles -induced cell death was observed through the leakage of reducing sugars and proteins in E. coli. Additionally, Silver nanoparticles have knack to demolish the permeability of the bacterial membranes via generating the pits and gaps, signifying that Silver nanoparticles could damage the structure of the bacterial cell membrane.[13,29]

3. Antifungal activity-

Fungal infections are more frequent in patients with immunosuppression and overcoming fungi-mediated diseases is a tedious process, because currently there is a limited number of antifungal drug. Consequently, the antifungal agents should be biocompatible, non-toxic, and environmental friendly. To overcome the problem, silver nanoparticles play an important role as anti-fungal agents against various diseases caused by fungi. Nano-silver illustrates effective anti-fungal activity beside clinical isolate and “ATCC” strains of “Trichophyton mentagrophytes” and “Candida” species with concentrations of 1-7 μg/mL. The antifungal activities depend on size of different silver nanoparticles were execute beside mature “Candida albicans” and “Candida glabrata” biofilms. Biologically synthesized silver nanoparticles shows antifungal activity against various phytopathogenic fungi, as well as *Alternaria alternata, Sclerotinia sclerotiorum, Macrophomina phaseolina, Rhizoctonia solani, Botrytis cinerea, and Curvularia lunata* at the concentration of 15 mg.[13,30]

4. Anticancer activity-

Cancer is widely occurring disease. Although many chemotherapeutic agents are currently being used on different types of cancers but the side effects are extensive and particularly administrations of chemotherapeutic agents by intravenous infusion are a tedious process. Therefore, it is necessary to develop technologies to avoid systemic side effects. To overcome the problem, many researchers are developing nano-formulations as an alternative tool for formulations to target tumour cells specifically. Starch coated silver nanoparticles shows anticancer activity which was studied on normal human lung fibroblast cells (IMR-90) and human glioblastoma cells (U251). Silver nanoparticles shows alterations in cell morphology which decreases cell viability as well as metabolic activity and increases oxidative stress which leads to increased production of reactive oxygen species (ROS), which leads to mitochondrial damage which leads to DNA damage. Among these two cell types, U251 cells showed more sensitivity than IMR-90. The similar group also confirmed the cellular uptake of silver nanoparticles mainly through endocytosis. Silver nanoparticles-treated cells shows various abnormalities, including upregulation of metallothionein, downregulation of major actin binding protein, filamin, and mitotic arrest. The “antineoplastic activities” of “protein-conjugated silver sulphide nano-crystals” are dependent on size 0 in human hepatocellular carcinoma Bel-7402 and C6 glioma cells. Instead of giving direct treatment of Silver nanoparticles into the cells, some researchers developed chitosan as a carrier molecule for delivery of silver to the target cancer infected cells. Bio-synthetic silver nanoparticles can alter cancer cell morphology, which is an early indicator for apoptosis. Apoptosis can be determined by structural alterations in cells by transmitted light microscopy.[13,31,32]

5. Antiviral activity of silver nanoparticles-

The overall world population is facing the problem of viral infection and the various life threatening diseases caused by different viruses, such as the common cold, influenza, hepatitis, chickenpox, human immunodeficiency virus, herpes keratitis, and viral encephalitis. Various medicines and vaccines against a number of viruses has been prepared. Although tremendous improvement has been made from time to time in the field of antiviral therapy, medicines cannot completely treat or prevent all viral disease. Hence, it is necessary to develop antiviral agents which can prevent the broad range of viruses. Herpes simplex virus types 1 and 2 (HSV-1 and HSV-2, respectively) and human parainfluenza virus type 3 (HPIV-3) can cause serious infection in humans. Available reports suggest that the mechanism to avoid the viral infection can be the inhibition of DNA replication.[14]

Silver nanoparticles have inhibitory activities against human immunodeficiency virus (HIV) and hepatitis B virus (HBV). The antiviral action of the Silver nanoparticles confirm that each scavenger cell (M)-tropic and T-lymphocyte (T)-tropic strains of HIV-1 were sensitive to the Silver nanoparticles-coated polyurethane condom (PUC). Even though, numerous studies have revealed that Silver nanoparticles could slow down the viability of viruses but the exact mechanism of antiviral activity is still not known. Biologically-synthesized silver nanoparticles 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 Silver nanoparticles. The mechanisms of viral replication are due to the interaction of Silver nanoparticles with the virion surface and the virion core.(13)

Textile Applications- The Nano materials are commercially used in textile industries by incorporating into fibre or coated with fibre, for instance Silver nanoparticles are used in T shirt, sporting clothes, undergarments, socks etc.(13)

Medicinal Textiles and Devices- Silver nanoparticles synthesized by using *A. dubius* counterfeited on the cotton cloth and perspiration pad samples express high resistance against sweat microorganism i.e. Corynebacterium. The Antibacterial drug activity of gauze fabric discs incorporated with silver nanoparticles reveal antimicrobial activity against Pseudomonas aeruginosa. Curcuma longa tuber dust enveloped silver nanoparticles manifested minimum bactericidal concentration (MBC) for Escherichia coli BL-21 strain at concentration 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. The incorporation of *Azadirachta indica* synthesized silver nanoparticles into cotton cloth results in antibacterial drug effect against *E. coli*.(15,33)

Significance of Silver nanoparticles in Food Industry- Silver nanoparticles is widely used in food industry reported by Cushen and co-workers chiefly due to antibacterial activity and preservative free. Minimum amount of Silver nanoparticles is safe for human use however harmful 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 the commercially available bag in which silver nanoparticles are applied. Silver nanoparticles are widely used in daily product that is soaps, food, plastics, pastes and textiles due to their anti-fungicidal and anti-bactericidal activities.(34)

Nanotechnology and food packaging- Nano-based "smart" and "active" food packaging is superior than conventional packaging methods because it provides better packaging material with improved mechanical strength, barrier properties and antimicrobial films to nano-sensing the pathogen detection and alerting the consumers for the safety status of food. The nanocomposites "an active material" for packaging and material coating can be used to improve the packaging of the food. Many researchers build awareness towards antimicrobial property of organic compounds i.e. essential oils, organic acids, and bacteriocins 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. Inorganic nanoparticles shows strong antibacterial activity in low concentration and can be more stable in extreme conditions. The "antimicrobial packaging" is active packaging that contacts the food product or the headspace inside which prevents the microbial growth present on food surfaces. Several nanoparticles such as silver, copper, chitosan, and metal oxide nanoparticles like titanium oxide or zinc oxide have been reported to have antibacterial property.(13,35)

Food processing- Some food processing techniques exploit enzymes to modify food components to improve their flavour, nutritional quality or other characteristics. The Nanoparticles used as a source to stabilize 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 to a porcine triacylglycerol lipase effectively hydrolysed olive oil. They facilitate the improvement in stability, reusability, and adaptability. Nano-charcoal adsorbent is a nanoparticle product used for the decolouration of food products.(36)

Environmental treatments-

Air disinfection- The Bioaerosols are airborne particles of biological origins, including viruses, fungi, bacteria, which can cause the infectious, allergenic or toxigenic diseases. Particularly, indoor air bioaerosols found to be accumulated in large quantities on filters of heating, ventilating, and air-conditioning (HVAC) systems. It is found that outdoor air pollution and insufficient hygiene of an HVAC installation often results in lower quality of indoor air. Moreover, the organic or inorganic materials deposited on the filter medium after air filtration can lead 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 minimized by the combining antimicrobial silver nanoparticles into air filters. The antimicrobial effect of silver nanoparticles on bacterial contamination of activated carbon filters (ACF) was studied by Yoon et al. The results showed that silver-deposited "ACF filters" can effectively remove 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 be adjusted to avoid excessive reduction of their adsorptive characteristics and to optimize effective antimicrobial activity. The presence of an antimicrobial AgNO3 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.(13,37)

In water purification-

A ceramic water filter (CWF) is a device that eliminates pathogens from the water. Currently, CWFs are manufactured by pressing and firing a mixture of clay and a burnable organic material such as flour, rice husks, or sawdust and then treated with Silver nanoparticles. The filter is formed using a filter press, after which it is air-dried and fired in furnace. This forms the ceramic material and burns off the sawdust, flour, or rice husk in the filters, which makes it permeable to water by formation of pores. CWFs are reported as effective in removing more than 99% of protozoa and 90-99.99% of bacteria from drinking water. Still, a high removal of viruses is not achieved. Silver nanoparticles and silver nitrate (AgNO3, Ag+) are added to filters at all CWF factories to achieve higher pathogen removal due to their antimicrobial properties. The silver solutions are applied to CWF either by brushing or dipping technique.

Two mechanisms of microorganism disinfection by CWFs were suggested.

(i) CWFs can remove microorganisms by size exclusion or adsorption;

(ii) Silver nanoparticles or Ag+ inside of CWFs can inactivate pathogens.(13,16,38)

REFERENCE-

1. Firdhouse MJ, Lalitha P. Biosynthesis of silver nanoparticles and its applications. J Nanotechnol 2015: 1–18.
2. Khaydarov RR, Khaydarov RA, Estrin Y, Evgrafova S, Scheper T, Endres C, Cho SY. Silver nanoparticles. InNanomaterials: Risks and Benefits 2009 (pp. 287-297). Springer, Dordrecht.
3. Tran QH, Le AT. Corrigendum: Silver nanoparticles: synthesis, properties, toxicology, applications and perspectives (Adv. Nat. Sci: Nanosci. Nanotechnol. 4 033001). Advances in Natural Sciences: Nanoscience and Nanotechnology. 2018 Dec 11;9(4):049501.
4. Güzel R, Erdal G. Synthesis of Silver Nanoparticles. Silver Nanoparticles-Fabrication, Characterization and Applications. 2018 Jul 18.
5. Zhang XF, Liu ZG, Shen W, Gurunathan S. Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches. International journal of molecular sciences. 2016 Sep;17(9):1534.
6. Natsuki J, Natsuki T, Hashimoto Y. A review of silver nanoparticles: synthesis methods, properties and applications. Int. J. Mater. Sci. Appl. 2015 Sep 29;4(5):325-32.
7. El-Nour KM, Eftaiha AA, Al-Warthan A, Ammar RA. Synthesis and applications of silver nanoparticles. Arabian journal of chemistry. 2010 Jul 1;3(3):135-40.
8. Nair LS, Laurencin CT. Silver nanoparticles: synthesis and therapeutic applications. Journal of biomedical nanotechnology. 2007 Dec 1;3(4):301-16.
9. Shameli K, Ahmad MB, Zamanian A, Sangpour P, Shabanzadeh P, Abdollahi Y, Zargar M. Green biosynthesis of silver nanoparticles using Curcuma longa tuber powder. International journal of nanomedicine. 2012;7:5603.
10. Sapsford KE, Tyner KM, Dair BJ, Deschamps JR, Medintz IL. Analyzing nanomaterial bioconjugates: a review of current and emerging purification and characterization techniques. Analytical chemistry. 2011 Jun 15;83(12):4453-88.
11. Lin PC, Lin S, Wang PC, Sridhar R. Techniques for physicochemical characterization of nanomaterials. Biotechnology advances. 2014 Jul 1;32(4):711-26.

12. Pantic I. Application of silver nanoparticles in experimental physiology and clinical medicine: current status and future prospects. Rev Adv Mater Sci. 2014 Jan 1;37:15-9.
13. Verma P, Maheshwari SK. Applications of Silver nanoparticles in diverse sectors. International Journal of Nano Dimension. 2019 Jan 1;10(1):18-36.
14. Elechiguerra JL, Burt JL, Morones JR, Camacho-Bragado A, Gao X, Lara HH, Yacaman MJ. Interaction of silver nanoparticles with HIV-1. Journal of nanobiotechnology. 2005 Jun;3(1):6.
15. Huang Y, Chen S, Bing X, Gao C, Wang T, Yuan B. Nanosilver migrated into food-simulating solutions from commercially available food fresh containers. Packaging Technology and Science. 2011 Aug;24(5):291-7.
16. Zhang H. Application of silver nanoparticles in drinking water purification.
17. Alexander JW. History of the medical use of silver. Surgical infections. 2009 Jun 1;10(3):289-92.
18. Christy AJ, Umadevi M. Synthesis and characterization of monodispersed silver nanoparticles. Advances in Natural Sciences: Nanoscience and Nanotechnology. 2012 Aug 2;3(3):035013.
19. Sakamoto M, Fujistuka M, Majima T. Light as a construction tool of metal nanoparticles: Synthesis and mechanism. Journal of Photochemistry and Photobiology C: Photochemistry Reviews. 2009 Mar 1;10(1):33-56.
20. Mafuné F, Kohno JY, Takeda Y, Kondow T, Sawabe H. Formation and size control of silver nanoparticles by laser ablation in aqueous solution. The Journal of Physical Chemistry B. 2000 Oct 5;104(39):9111-7.
21. Manno D, Filippo E, Di Giulio M, Serra A. Synthesis and characterization of starch-stabilized Ag nanostructures for sensors applications. Journal of Non-Crystalline Solids. 2008 Dec 15;354(52-54):5515-20.
22. Zhang J, Langille MR, Mirkin CA. Synthesis of silver nanorods by low energy excitation of spherical plasmonic seeds. Nano letters. 2011 Jun 8;11(6):2495-8.
23. Im SH, Lee YT, Wiley B, Xia Y. Large-scale synthesis of silver nanocubes: the role of hcl in promoting cube perfection and monodispersity. Angewandte Chemie International Edition. 2005 Mar 29;44(14):2154-7.
24. Dang VP, Vo TK, Nguyen TK, Nguyen ND, Nguyen DC, Bui DD, Bui DC, Nguyen QH. Synthesis and antimicrobial effects of colloidal silver nanoparticles in chitosan by c-irradiation. J Exp Nanosci. 2010;5(2):169-79.
25. Tomaszewska E, Soliwoda K, Kadziola K, Tkacz-Szczesna B, Celichowski G, Cichomski M, Szmaja W, Grobelny J. Detection limits of DLS and UV-Vis spectroscopy in characterization of polydisperse nanoparticles colloids. Journal of Nanomaterials. 2013;2013.
26. Desimoni E, Brunetti B. X-ray photoelectron spectroscopic characterization of chemically modified electrodes used as chemical sensors and biosensors: a review. Chemosensors. 2015 Jun;3(2):70-117.
27. Bootz A, Vogel V, Schubert D, Kreuter J. Comparison of scanning electron microscopy, dynamic light scattering and analytical ultracentrifugation for the sizing of poly (butyl cyanoacrylate) nanoparticles. European journal of pharmaceutics and biopharmaceutics. 2004 Mar 1;57(2):369-75.
28. Dobrovolskaia MA, Germolec DR, Weaver JL. Evaluation of nanoparticle immunotoxicity. Nature nanotechnology. 2009 Jul;4(7):411-4.
29. Baker C, Pradhan A, Pakstis L, Pochan DJ, Shah SI. Synthesis and antibacterial properties of silver nanoparticles. Journal of nanoscience and nanotechnology. 2005 Feb 1;5(2):244-9.
30. Kim JS, Kuk E, Yu KN, Kim JH, Park SJ, Lee HJ, Kim SH, Park YK, Park YH, Hwang CY, Kim YK. Antimicrobial effects of silver nanoparticles. Nanomedicine: Nanotechnology, Biology and Medicine. 2007 Mar 1;3(1):95-101.
31. Gopinath P, Gogoi SK, Chattopadhyay A, Ghosh SS. Implications of silver nanoparticle induced cell apoptosis for in vitro gene therapy. Nanotechnology. 2008 Jan 29;19(7):075104.
32. AshaRani PV, Low Kah Mun G, Hande MP, Valiyaveettil S. Cytotoxicity and genotoxicity of silver nanoparticles in human cells. ACS nano. 2009 Feb 24;3(2):279-90.
33. Muthuswamy S, Krishnamurthy S, Yun Y. Immobilization of silver nanoparticles synthesized using Curcuma longa tuber powder and extract on cotton cloth for bactericidal activity. Bioresource technology. 2010;101(20):7958-65.
34. El-Molla MM, El-Khatib EM, El-Gammal MS, Abdel-Fattah SH. Nanotechnology to improve coloration and antimicrobial properties of silk fabrics.

35. Lamba A, Garg V. Nanotechnology approach in food science: A review. Nanotechnology. 2018 Mar;3(2).
36. Singh T, Shukla S, Kumar P, Wahla V, Bajpai VK, Rather IA. Application of nanotechnology in food science: perception and overview. Frontiers in microbiology. 2017 Aug 7;8:1501.
37. Miaśkiewicz-Peska E, Łebkowska M. Effect of antimicrobial air filter treatment on bacterial survival. Fibres & Textiles in Eastern Europe. 2011;19(84):1.
38. Pradeep T. Noble metal nanoparticles for water purification: a critical review. Thin solid films. 2009 Oct 30;517(24):6441-78
39. Rahman S, Rahman L, Khalil AT, Ali N, Zia D, Ali M, Shinwari ZK. Endophyte-mediated synthesis of silver nanoparticles and their biological applications. Applied microbiology and biotechnology. 2019 Mar 15;103(6):2551-69.