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Applications of Silver Nanoparticles: A Review

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ABSTRACT: Nanotechnology is the most acclaimed art of science in recent times. It deals with the structure of matter having dimensions ranging to a billionth of a meter. Nanotechnology studies the exclusive properties of an element from the core of its size and shape to be exploited for the benefit of science and technology. Silver (Ag) a transition metal, has evolved from its ornamental value, to application in various fields of science and technology with its nano scale profile (nanometer: nm) as Silver nano particles (Ag-NPs).The present paper discusses a brief insight on silver metal, having documentation of its beneficial applications in traditional Chinese and Indian Ayurvedas since 1000BC.

Keywords: Nanotechnology; Silver nanoparticles (AgNPs) and nanometer (nm).

INTRODUCTION: It is a rendition of a famous saying, "Big things comes in small packets", compliments the wide application and benefits of various elements in their nanoscale profiles, vigilenced by Nanotechnology. A nanometer (nm) is one billionth of a meter of material or particle with external dimensions in the size range 1nm-100nm; down to the size of atoms about 0.1 nm. Nanoparticles are unique because of their large surface area and this property dominates the contribution made by the small bulk of the material.

In this brief review, the silver nanoparticles ranging between 1nm and 100nm have been discussed. The beneficial property of silver nanoparticles is commendable for its application in textile, medical, and food industry.

SILVER NANOPARTICLES APPLICATION IN TEXTILE INDUSTRIES: The flourishing nanotechnology industry is exuberantly discovering novel techniques and nano materials that are being used for consumer product. There has been a compiled report listing more than 500 consumer products that claims to include some form of engineered nanoparticles[1]. Textile industry employs the use of silver nanoparticles up to 20% in most of its products like socks, bandages, paints and food containers to exploit the antimicrobial properties of Ag-NPs as it restricts the growth of odor causing bacteria.[2–10] Silver nanoparticles has been harnessed as antimicrobial agent on E. Coli[2] and successfully reported to curtail the growth of harmful Gram- negative bacteria.

The silver nanoparticles coated polyurethane foam has been utilized as an antibacterial water filters.[11] Several researchers have fabricated antibacterial textile fibers loaded with silver nanoparticles via "Green Approach" for excellent laundering durability along with antibacterial property.[6] The size of Ag-NPs was reported to have ~20nm; and its antibacterial activity was evaluated against Gram-negative Escherichia Coli bacteria. The reported results showed excellent antibacterial activity by the incorporation of 2% leaf extracts on cotton fibers. These fibers have also exhibited superior antibacterial activity even after several washings indicating their usage of these textile products for medical and infection prevention application. There are reported literature where antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics have been documented where by the reduction of silver ions by using Fusarium oxysporum to generate stable gold or silver nanoparticles in water. These particles can be incorporated in several kinds of materials such as cloths. The cloths with silver nanoparticles are sterile and can be useful in hospitals to prevent or to minimize infection with pathogenic bacteria such as Staphylococcus aureus.[12] There has been a new approach to antibacterial treatment of cotton fabrics with silver nanoparticles using sol-gel process by Abidi *et al.*[13], which can be a useful alternative for preparing antibacterial textile product. There are studies by various researchers using Sonochemical coating i.e. ultrasound irradiation of silver nanoparticles on textile fabrics, (Nylon, Polyester and cotton)and aggregations of Ag-NPs on polymer matrix reported the antibacterial activity studies have excellent resistant against E. Coli (Gram negative) and Staphylococcus aureus (Gram positive) cultures.[14,15]

SILVER NANOPARTICLES APPLICATION IN MEDICINES: Nanotechnology has open new avenues to curb diseases using atomic scale tailoring of metals for high performance applications. The size of nano material is similar to that of most biological molecules and structures, making nano materials useful for both in vivo and in vitro biomedical research and applications. Coordination of nanotechnology with biomedical research has led to the development of various analytical tool and techniques for drug delivery systems.[16] It is reported that the nanoparticles increase chemical activity due to crystallographic surface structure with their large surface to volume ratio, silver nanoparticles is a new scope to the long used silver for the treatment of burns, wounds and several bacterial infection.[17–20]

Recent applications of Ag-NPs have made its impact on imaging,[21] sensing,[22] targeted drug delivery,[23] gene delivery systems,[24] artificial implants.[25] The preparation of silver nanoparticles in the range of 10-15 nm with increased stability and enhanced anti-bacterial potency have been reported by Shrivastava *et al.*[26]. The action of Ag-NPs as an antibiotic comes from the fact that it is a non-selective toxic “biocide”. Silver based antimicrobial biocides are used as wood preservatives. In water usage, silver and copper based disinfectants are used in hospital and hotel distributions systems of laundries to control infectious agents. Hebeish *et al.*[27] has reported that Ag-NPs of 22nm size value when treated with cotton fabrics containing 250ppm. Ag-NPs were more effective against different species of organisms than those containing 60 and 125ppm. The results of potent healing using fabrics treated with 250ppm of Ag-NPs indicate that it leads to similar results compared with that of the Dermazin cream. Moreover the anti-inflammatory effect of Ag-NPs is nearly similar to 20ml dose of the reference Indomethacin drug. Mekkawy *et al.*[28] have reported in-vitro and in-vivo evaluation of drug release and antibacterial activity of a silver-loaded wound dressing coated with a multilayer system to heal wounds faster than normal pace. Several reports on salts of silver and their derivatives are commercially employed in the form of metallic silver, silver nitrate and silver sulfadiazine as antimicrobial agents[29] composites for use of disinfecting filters[11] and coating materials. Mishra *et al.*[30] have reported that Ag-NPs and Ag^+ carriers can be beneficial in delayed diabetic wound healing as diabetic wounds are affected by many secondary infections. These nanoparticles can help the diabetic patient in early wound healing and minimal scars recovery. S. Prasad *et al.*[31] in their findings have reported about the significance of colloidal silver (electrical silver atoms) which appears to be a powerful, natural antibiotic and preventative against infections. Acting as a catalyst, it reportedly disables the enzymes that one-celled bacteria, viruses and fungi needs for the oxygen metabolism. They target these disease causing foreign bodies without harming human enzymes or parts of the human body chemistry. This results in the destruction of disease causing organism in the body and in the food. Baker *et al*.[32] have reported that silver nanoparticles were found to be completely cytotoxic to E. Coli for surface concentration as low as 8µg of Ag/cm^2.

SILVER NANOPARTICLES APPLICATION IN FOOD INDUSTRY: Nanoparticles were used in textiles, as delivery systems for drugs and now they find their use in food industry in a similar fashion. Nanoparticles such as silicate nanoparticles, zinc oxide and TiO_2 are used to reduce the flow of oxygen inside the packaging containers. Similarly silver nanoparticles and silver coatings can provide anti-microbial properties with other materials being used as oxygen and UV scavengers. There are numerous reviews on the protection of meat, fruit and dairy products against the most common food pathogens by Ag-NPs-doped non-degradable and edible polymer and oils in order to increase the fresh food shelf life. The uses of Ag-NPs have been evaluated in terms of Ag^+ migration into the packed food.[33] Other emerging metal nanoparticles with biocidal properties are Cu, Zn, Au, Ti and Ag. Among them silver nanoparticles demonstrated to have the most effective bactericidal properties against a wide range of pathogenic microorganisms including bacteria, yeasts, fungi and viruses.[17] Ag-NPs showed better antimicrobial properties compared to metallic silver due to their extremely large surface area which can provide a better contact with the microorganism. Furthermore they exhibit low volatility and stability at high temperatures.[34] Although the use of Ag-NPs as antimicrobial agents in food packaging is a mature technology, concerns on the risk associated with the potential ingestion of the Ag ions migrated into food and drinks still exists. This leads to a cautious attitude of food safety authorities. The exhaustive use of silver nanoparticles in polymer matrix for packaging as LDPE (Low density polyethylene) with Ag & ZnO NP's for orange juice.[35] LDPE with Ag-NP's for barberry[36], LDPE with (AgNP's+TiO_2+Kaolin) for strawberry[37], PVC (polyvinyl chloride)+Ag-NP's for minced beef[38], EVOH (ethylene vinyl alcohol) for chicken, pork, cheese, lettuce, apples, peels, egg-shells[39], polyurethane & Ag-NP's for fresh apples, white sliced bread, fresh carrots, cheese, milk powder, fresh orange juice[40], (polyethylene+Ag,TiO_2)NP's included under nano-composites packaging based on Ag-NP's degradable polymeric matrices.[41] The use of nano-composites packaging based on Ag-NP's+ biodegradable edible polymeric matrices includes cellulose +Ag-NP's for fresh cut melon[42], beef and meat.[43] The use of Pullulan an edible polysaccharide polymer consisting of maltotriose units has now become the most affordable packaging material along with Ag-NP's for Turkey meat[44] , meat and poultry products.[45] The nano-composite of calcium alginate +Ag montmorillonite NP's finds its application for packaging of fresh cut carrots.[46] The Agar hydrogel + Ag montmorillonite NP's for cheese[47], Sodium alginate + Ag NP's for pears and carrots[48], also the nano-composite of Sodium alginate +Ag montmorillonite NP's[49] and (Sodium alginate + $CaCl_2$ + Ag-NP's) for cheese packaging[50]. The use (Ag-NP's + starch)[51] and (Ag-NP's + starch + sodium alginate + lemon grass oil) have property for preventing growth of S. Aureus, E. Coli, Candida albicans in packed food material.[52] The Ag-NP's upholds favoured criteria as food packaging material.

Despite all above applications of Ag-NP's in food industry its adverse effects could not be easily curtailed. An exhaustive study was made by several researchers and Echegoyen and Nerin[53] reported their studies on the migration of silver to different types of nano-composites (LDPE and polypropylene) into food stimulants. The reported results highlighted the migration of silver was dependent on the pH and temperature profile of the product. Cushen *et al.*[54] studied the effect of time and temperature on the migration of silver and copper from polyethylene (PE) nano-composites to boneless chicken breasts. Migration of silver occurred in a range from 0.003 to 0.005mg/dm^2 and that of Cu in a range from 0.024 to 0.049 mg/dm^2.

SILVER NANOPARTICLES APPLICATION IN ENERGY APPLICATIONS: With the inception of surface plasmons (SPs) technology, many researchers have used Ag-NP's metal/polymer nano composites for enhancing the efficiency of solar cells. The incorporation of silver nano particles (coupled with InAs/GaAs) have been reported for enhancing the overall power conversion efficiency enhancement and the spectral response of solar cells due to efficient light scattering and trapping by surface plasmon generated in broad band absorption enhancement[55]. Nourolahi et al[56] utilized the optimal concentration of silver nano particles to the TiO_2 based solar cells which improved the power conversion efficiency of fabricated cell. It is reported that the incorporation of silver nano particles effectively, extended the optical pathway of incident light which increased the photo absorption of photo active layer. The role of Ag-NP's has been extensively exploited for high frequency electronic application, non-linear optics, spectral selective coatings for solar energy absorption and bio labeling.[57]

SILVER NANOPARTICLES APPLICATION IN POLUTION CONTROL: Nano technology has extended its contribution in the area of pollution sensing and prevention by exploiting its novel properties to be a resource of Green Chemistry. The various properties of nano particles viz. large surface area, high surface energy, ability to absorb various metal pollutants and contaminants through in-situ or in-vivo remediation apart from ex-situ or in-vitro applications. Nano sensors are also capable of detecting microbes, humidity and toxic pollutants at very minute level.[58,59] It has been reported that the hybrid carbon nano tubes along with silver nano particles has gain significance as antibacterial material as the toxicity of silver nano particles was much reduced when incorporated with carbon nano materials as Ag-NP's were unable to release themselves into the environment.[60,61] Despite the growing commercialization of Ag-NP's, the knowledge of its adversity on environmental effect cannot be neglected.[62] Ionic silver is highly toxic to aquatic organisms.[63,64] The reported results shows that Ag-NP's has a toxic effect on cells suppressing cellular growth and multiplication, causing cell death depending on concentration and duration of exposure time. It caused cell-type specific DNA damage, with possible implications on reproductive health systems of humans. The Ag-NP's (20 nm and 200 nm) over different concentration and time periods, inhibited normal cell function, caused more cell death than the titanium dioxide nanoparticles. In particular, the 200 nm Ag-NP's caused a concentration dependent increase in DNA damage in the human cell. The chronic effects of silver on an organism can appear in various systems like, disruption of reproduction, slower growth or toxicity to early life forms. Silver toxicity to aquatic plants and animals is correlated with the concentration of "free" ionic silver in freshwater[65]. The United Environmental Protection Agency (USEPA) has set water quality criteria values for silver in salt and fresh water at 1.9 and 3.4 ppb respectively. The USEPA has also instituted a secondary drinking water standard for silver of 100ppb. The effect of exposure data and toxicity for not only silver nanoparticles[66,67] but also other elements used as nanoparticles should be the current Nanotalk to be kept under surveillance.

CONCLUSION: Nanotechnology can be beneficial to society only with the application of LCA (Life Cycle Assessment). LCA is defined as "An objective process to evaluate the environment burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, being used to evaluate and implement opportunities for environmental improvements.[68] The role of nanotechnology can only be a remarkable discovery of science if before the implementation of its products, it monitors control and incorporation of sustainability matrices into the nanotechnology.

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