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SILVER NANOPARTICLES IN VARIOUS BIOMEDICAL AND INDUSTRIAL APPLICATIONS

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Abstract

The term "nanotechnology" has emerged over the past two decades as more significant than other technologies for precise target delivery in medicine, agriculture, and other fields. In the meantime, scientists are creating various kinds of nanoparticles, including coated, metal, polymer, non-polymer, and chemically mediated ones. This particular silver nanoparticle is the most well-established in various fields. Because of its size, Ag NPS development and use hold the most promise. Target drug delivery in medicine and agriculture has been made more difficult by the emergence of numerous microbial infectious diseases. However, some requirements still need to be met by the available sources. In various countries, Ag NPs are used as a product in more than 23.99% of cosmetics, 33.99% of textiles, 15.89% of construction, 50.10% of medicine, 41.76% of environmental remediation, and 36.67% of agriculture.Additionally, Ag NP had a higher capacity for sustainability and recycling than other particles. Furthermore, compared to other NPs, biologically synthesized Ag NPs improve sperm motility in rats. This chapter focuses on "Silver Nanoparticles: Technological Advances, Research Trends, and Application" in depth.

Keywords: Agriculture Ag NPs, Medicinal Ag NPS, Ag NP, Sperm Motility, Nanotechnology

Introduction

Oxidant and antioxidant balance is necessary to maintain cell homeostasis for proper functioning. Homeostasis imbalance leads to poor biological function or damage to cells leads to death. Due to deficency of certain intrinsic (vitamins, minerals, enzymes and co-factors) and extrinsicn(radiation, occupatiuonal exposure, pollution, drug allergy) fcatorsfavours to enhance the reactive oxygen species production which will turn to generates free radicals. Those excess of radicals ions fuse to damages the inner cell membrane of lipid peroxidation. Peroxidation in cell membrane alters the pathophysiology of cells leads to impaired redox potential. Despite the membrane assembly by lipid bi-layers and PUFA degradation causes cell death or impaired homeostasis due antioxidant:oxidative species alteration. Different types of treatment/medications are available to treat the or to reverse the membrane potential and its assembly. However due to poor delivery to the target or cost-effective, less specificity with time consuming are the major drawbacks were faced so far untill the introduction of Nanoparticles. Nanoparticles get their name from their nanosize range of 0-100 nm and are invisible to the human eye. Recently, it has been demonstrated to serve essential tasks, particularly in the mechanical, electrical, vehicle, chemical, and biomedical pharmaceutical industries.Due to their size, diameter, surface area, and volume, nanoparticles display distinctive physical characteristics. Nanoparticles have incredibly high surface area and volume ratios regardless of their chemical makeup (Rudi et al.,2014). As a result, the structure of the nanoparticle surface affects a number of the physical characteristics of the nanoparticles, including solubility and stability. High surface area-to-volume ratios are necessary for applications like catalysis (Sharma et al.,2018). In addition, metal and metal oxide based nanoparticles have beneficial effect on environmental and biomedicine. Hence, based on last two decades data's, silver nanoparticle (AgNPs) as the one among other metal based NPs were most experimented in the field of biomedicine, agricultural and clinical fields. Though this AgNPs synthesized from the sources like microbe, various parts of the plants, or from the soil has shows extancial activity in the healthcare strategies and to reduce toxicity towards exact target. Hence, the present review aimed to discuss the silver nanoparticles and its biomedical applications towards target drug delivery.

results from biomedicinal activity of Silver Nanoparticles due to its unique physiochemical characters. As a result, the structure of the nanoparticle surface affects a number of the physical characteristics of the nanoparticles, including solubility and stability. High surface area-to-volume ratios are necessary for applications like catalysis (Sharma et al.,2018). Still, silver's features change at the nanoscale—for instance, spherical silver nanoparticles' remarkable capacity to scatter visible light results from their Plasmon resonance. Silver nanoparticles can be fabricated in various sizes and forms, and different manufacturing processes can be used to create silver spheres, rods, wires, and plates (Shenashen et al.,2014). Spherical silver nanoparticles can have a variety of forms and sizes, and isotropic shapes are generated in the stabilizing polymer. For instance, the silver nanoparticle formulations from nanocomposite contain fewer faceted silver nanoparticles, reducing the diversity in each nanoparticle's optical characteristics (Azharuddin et al.,2019)has most Still, silver's features change at the nanoscale—for instance, spherical silver nanoparticles' remarkable capacity to scatter visible light results from their Plasmon based on the biomedical resonance.

Toxicological and Risk aspect of Silver nanoparticles impact on spermatozoa of human male reproduction as an in vitro & in vivo studies

Nanoparticles have been utilized to improve sperm selection, XY cell sorting, sperm sexing using ultracentrifugation, and cryopreservation of sperm cells from various species, including farm animals. It is also important to stress that when we select various NPs versus sperm cells, surface molecules' size, external volume, shape, composition, and functionalization are essential for efficiency. Gold, superparamagnetic iron oxide, chitosan, and various other compounds have been utilized in treating cancer, diabetes, and other disorders. The XY genome's reproductive system, on the other hand, is limited. As established by Perez-Duran et al., 2020, silver nanoparticles are the best for preserving sperm or sperm as an antibiotic instead of commercial antibiotics against microbial contamination and avoiding excess ROS production during storage. According to numerous studies, AG NPs are employed for antibacterial, anti-inflammatory, and medicinal applications. It was stated that Ag NPs are primarily employed to cure cancer in vitro and in vivo studies.

Furthermore, Lafuente et al. (2016) found that 100mg of polyvinyl pyrroline-coated Ag NPs on adult Sprague Dawley rats do not affect sperm motility. However, there is an increase in aberrant sperm cells if the dosage is more significant than 100 mg/kg body weight. Thakur et al. (2014) discovered that male Wistar rats were exposed or treated orally with Ag NPs, and their detailed histological characteristics, such as a double head and a long tail attached with a mismatch hook or no hook during spermatogenesis, were all defined. Although previous histological investigations reveal that atrophy in seminiferous tubules, which leads to necrosis, induces spermatogenesis deprivation in Sertoli cells, there is an alteration in ultrastructure caused by seminiferous tubule atrophy. Orally administered Ag NPs (60-70 nm in size) on male Wistar rats every 12 hours for 48 days results in loss of spermatid number and spermatogonial cycle, which causes loss of sperm cell count if the dosage exceeds 75 mg/kg body weight (Miresmaeilie et al., 2013 &Sleiman et al., 2013). In reality, the Ag-NPs treatment for infertility is ineffective against reactive oxygen species. In general, Ag NPs increase the generation of ROS in the seminiferous tubules, damage the spermatogonial in Sertoli cells, and result in poor sperm quality. Although most studies revealed oral dosages (25-200 mg/kg body weight) of 60-80 nm-sized Ag NPs on male Wistar rats for more than six days to 146 days of the study period, silver ions induce the cellular membrane and affect enzymatic antioxidant secretion such as SOD, catalase, and glutathione peroxidase by generating H2O2 (Beer et al., 2012; Chen et al., 2013; Dedes et al., 2012 &Kyjovska et al., 2013).

Meanwhile, it promotes the formation of free radicals in the cellular membrane and compromises the integrity of the mitochondrial membrane, resulting in enzymatic antioxidants, most notably catalase. Another New Zealand study by Olugbodi et al.

(2020) found that administering Ag NPs (0.6 mg/kg body weight) to New Zealand white male rabbits for 126 days resulted in no weight growth, no sperm ejaculation, and no decrease in serum testosterone. Meanwhile, no histological or testis ultrastructure changes were identified in the test group compared to the control participant. However, Castellini et al. (2014) revealed differences and malfunctions in the spermatogenesis cycle in Ag NPs treated compared to the control group. Yttrium oxide nanoparticles (YO-NPs) reversed Ag NPs-induced testicular and spermatogenetic damage, according to a recent study by Gasam et al. (2021). As a result, the investigations reveal that instead of being utilized directly on an animal model and resulting in morphological toxicity, it can be employed as an extender or medium for sperm cell preservation, known as cryopreservation. A recent study found that plant-mediated zinc oxide nanoparticles better protect sperm cells during preservation, and no such action was found by Ag or Au nanoparticles (Parameswariet al., 2023). It was discovered that cryopreservation, due to its antioxidant properties, aids in cell survival and acts against ROS generation (Al Masud et al., 2021).

Furthermore, ROS production was significant during preservation, so Ag NPs can better protect against ROS. Ag NPs that use prepared extenders benefit from simplified methods for enhancing sperm during cryopreservation. At the same time, no investigations using Ag NPs as a cryomedium against ROS in sperm cell preservation have been conducted. Researchers and scientists may have taken steps to address this issue in the future.

Ag NPs as a biomedicne in Health impact and Environmental aspects in recycling of biowastes

Ag NPs have recently been extensively studied for their promising anticancer effects in various human cancer cell lines, including endothelium cells, IMR-90 lung fibroblasts, U251 glioblastoma cells, and MDA-MB-231 breast cancer cells (Kumar et al., 2016; Samdavid et al., 2020 &Odeniyi et al., 2020). Ag NPs may bind to mammalian cells and easily penetrate them via energy-driven internalization routes. Another appealing feature of Ag NPs is their unique fluorescence, which makes them good candidates for detection and dosage increase in X-ray irradiation applications. Theranostics, or the integration of therapy and diagnosis, is the most essential, appealing, and challenging method accepted by healthcare practitioners and researchers in successful and individualized cancer treatment (Nethi et al., 2020). Ag nanoparticles are also plasmonic structures, capable of scattering and absorbing light in specific locations. AgNP-derived dispersed light can be used for imaging after selective uptake into malignant cells, whilst absorbed light can be employed for selective hyperthermia(Herea et al., 2023). Much research has recently focused on analyzing the effects of Ag NPs on various types of cells found in the complex vascular system(Bian et al., 2019; Hu et al., 2021 & Malik et al., 2018). However, the published results needed to be more consistent. However, the collected data can contribute to society's treatment of vascular diseases, vasopermeability, and angiogenesis by providing substantial knowledge about the potential benefits of Ag NPs for pathological and physiological stages related to the cardiovascular system(Ikeda et al., 1999 & Gomes et al., 2021). Cardiovascular diseases, such as hypertension, may impact the harmful effects of Ag NPs. The first silver-modified cardiovascular medical device was a prosthetic silicone heart valve coated with elemental silver, which was developed to prevent valve-related bacterial infection and minimize the inflammatory response(Nemmar et al., 2023 &Talapko et al., 2020). Malaria, one of the most common infectious diseases in tropical and subtropical areas, has become a primary global healthcare concern((Arjunan et al., 2012 & Chen et al., 2016). It has been demonstrated that Ag NPs have a substantial effect against the malaria pathogen (Plasmodium falciparum) and its vector (Anopheles female mosquito (Mohammad et al., 2021). The translation of silver-based nanotechnology to clinical applications necessitates not only the development of safe, simple, eco-friendly, and cost-effective silver nanoparticle synthesis methods but also a thorough understanding of the related physicochemical peculiarities, in vitro and in vivo effects, bio-distribution, safety control mechanisms, pharmacokinetics, and pharmacodynamics of Ag NPs (Figure 1).

Figure 1 : Silver Nanoparticles in Various Medicinal and Accessaries

Ag NPs in Environmental aspects and in commercial products

According to contemporary nano databases, emerging trends of Ag NPs based on their nanosize in different industries, particularly medicines, are highly valued. Ag NPs are the most promising nanomaterials currently and as a commercial product. The famous visionary lecture "There is Plenty of Room at the Bottom," given by American physicist Richard Feynman in 1959, is thought to have given conceptual birth to the area of nanotechnology. It is unavoidable in nearly all fields of science, including medicine, the environment, agriculture (Figure 2), and engineering (Figure 3) (Feynman R et al., 1959). Nanotechnology makes use of both biological and inorganic materials, as well as hybrid materials. Because of their antibacterial properties, humans have used metals such as silver and copper for centuries, and their applications in consumer products such as textiles, shampoo, hygiene products, and contraceptives are currently being investigated. Significant global production of Ag NPs has been in recent years, and the global nanotechnology sector is predicted to continue to increase dramatically. In particular, the output of Ag NPs is predicted to reach 800 t by 2025. Because of the antibacterial capabilities of ionic silver, Ag NPs have a higher marketing value than other NPs. Ag NPs' high electrical and thermal conductivity, surface-enhanced Raman scattering catalytic activity, and non-linear optical features have resulted in the development of novel products and a wide range of scientific applications (Thwala et al., 2021 & Zhang et al., 2023).

Figure 2: Silver Nanoparticles in Agriculture

Figure 3: Silver Nanoparticles in Constructions/Civil Engineering

Because of their physicochemical properties, Ag NPs are used as antiseptic agents in medical, cosmetics, food packaging, bioengineering, electrochemistry, and catalysis industries(Guimor et al. & Ramos et al., 2020). One of the primary reasons for the use of Ag NPs in the formulation of surface cleaners, toys, textiles, air and water disinfection, antimicrobial catheters, antimicrobial gels, antimicrobial paints, food packaging supplies (Figure 4), clinical clothing, food preservation, and so on is their antibacterial and antimicrobial activity (Beyene et al., 2017). Ag nanoparticles of various shapes and sizes are employed to create a quick point-of-care diagnostic instrument for the field-forward screening of severe acute febrile infections such as dengue, yellow fever, and the Ebola virus(Elumalai et al., 2017). Another noteworthy application of Ag NPs is their inclusion in textile products. Simple and appropriate cotton fabrics with tunable colours, antibacterial capabilities, and self-healing superhydrophobic qualities can be protective gear for working in moist and unsanitary situations (Han et al., 2021 & León-Silva et al., 2016). This application proposes a green synthesis technique for producing Ag NPs by employing quercetin (a polyphenolic flavonoid) via deposition of branching poly(ethylenimine) (PEI) Ag NPs and fluorinated decyl polyhedral oligomericsilsesquioxanes on cotton fabrics.

Figure 4: Silver Nanoparticles in Food Industries

Microbial mediated Silver Nanoparticles in Dye degradation - As an environmental Bioremediation aspect

Ag NPs aid in the degradation of pollutants such as crystal violet, methylene blue, and malachite green, and it has also been discovered that TiO2/Ag, ZnO/Ag, and NiO/Ag have higher photocatalytic activity than metal oxides, as well as the degradation of pollutants such as the colourful methyl orange and the colourless toxic 4-chlorophenol(Hrostea et al., 2021 & Hwang et al., 2021). The bactericidal membrane produced for water purification by impregnating nitrocellulose membrane filters with one mg/L of biosynthesized Ag NPs results in total inhibition of the microbial population of E. coli, Enterococcus faecalis, Pseudomonas aeruginosa, and S. aureus suspensions Inactivation and elimination of E. coli and S. aureus reached 6 and 5.2 orders of magnitude, respectively (Gupta et al., 2013).

Advanced risk in diagnosing cancer and Wound healing agent of Ag NPs

Further research into the anticancer mechanisms of Ag NPs is required to develop cost-effective, dependable, and broad-spectrum anticancer medicines (Saratale et al.,2018). Aside from the most well-studied antibacterial and anticancer actions, Ag NPs have garnered interest in various cutting-edge medical applications such as dental material filling, vaccine adjuvants, and bioimaging (Rehman et al.,2022). It has recently been demonstrated that Ag NPs can be successfully used in multiple pharmaceutical formulations to design and manufacture wound and burn dressings, ointments, antibacterial garments, and medical device coatings (Burdușel et al.,2028). Size, shape, concentration, surface charge, and colloidal state are important physicochemical characteristics that influence the antibacterial properties of Ag NPs (Dakal et al.,2016). Silver nanoparticles kill bacteria via a Trojan horse mechanism, whereby their initial attachment to the cell surface alters permeability and impairs cellular respiration, followed by cell-barrier penetration and intracellular metallic silver ion release (Reidy et al.,2013). Ag NPs have bactericide or bacteriostatic activity against biofilm-organized microorganisms due to intrinsic activity against isolated or blocked cells, destabilization or disruption of the exopolymeric substances within the extracellular biofilm matrix, or interfering with bacterial signalling molecules. Nanoparticles have attracted much interest in developing novel and improved drug-delivery systems for improving current human healthcare practices (Shrivastav et al.,2013). AgNP-based nanosystems were assessed as potential carriers of anti-inflammatory, antioxidant, antibacterial, and anticancer compounds. To create unique and performance-enhanced drug delivery systems that respond to thermal, optical, or pH modification to treat inflammatory, infectious, and malignant diseases, hybrid molecular units of Ag NPs must be successfully chosen (Karade et al.,2021). Ag NPs were successfully assessed as effective anti-tumour drug-delivery systems, operating as passive or active nanocarriers for anticancer medicines. AG NPs were prepared using various techniques, including organic-water two-phase synthesis, micro-emulsion, radiolysis, and, most often, reduction in aqueous solution (Benyettou et al.,2015). Recent research has demonstrated the potential utility of Ag NPs as vaccine and medication carriers for targeted and selective cell or tissue targeting (Ghosh et al.,2022).

Ag NPs in consumer products as per Nano databases - As an Environmental aspects

Ag NPs-based products have appeared in various consumer products, and according to the Nano Product Database, 1628 nanosilver products are developing trends. With its contamination, the ancient physician and father of medicine, 'Hippocrates,' discovered that silver heals wounds and fights microbial infections. It also needs to be determined whether people will be exposed to higher doses of silver. Besides other countries, India's nanosilver market for the previous year was 61.6 million in 2019, with a forecast of 208.7 million may increase by early 2020 (Butt et al., 2021; Merkel. 2016 &Laperche et al., 2019). Nanosilver and its 1 to 100 nm size range are advantageous for various electrical and thermal applications and optically defined products such as biological and chemical sensors. It is also utilized as a diagnostic device due to its unique nano-optical properties and photonic catalyst, antimicrobial coat, textiles in leading silver copper jari silk, wound healing powder, biomedical tools, and many other applications (Liang et al., 2021 & Qian et al., 2020). Although Ag NPs produce a small number of Ag ions and compromise release a small quantity when scavenging against illnesses such as bacterial infections and their associated inflammation, it was shown that because of their nano-sized particles, they could attack and destroy germs(Abdellatif et al., 2022 & Bold et al., 2022). Recently, it was reported that an increase in demand for nanosilver-based products increased the various emerging trends in medicine. In contrast, industries as a significant economy expect the growth of India to not depend on others during estimation (Dhanker et al., 2022 & Kumar et al., 2020). Also, due to overpopulation, the increased demand for electronics items, chips, silver batteries, and Indian pharmaceutical industries is projected to fuel growth in the coming days (Figures 5 & 6).

Figure 5 Silver nanoparticles in Textile Industries

Figure 6 Silver nanoparticles in Skin and Hair Care Products as per Nano database

Meanwhile, there is a concern that silver nanoparticles and their impact on environmental growth may hinder the evolution and progression of the economy by analyzing frame time. On the other hand, it needs to create awareness about synthesizing silver nanoparticles by biological/biogenic procedures and its related applications in various fields. On the other hand, raising awareness about producing silver nanoparticles using biological or biogenic processes is necessary to lessen their harmful influence on the environment and their relevant uses in numerous industries.

Conclusion

Silver and silver nanoparticle-based compounds are effective against various ailments, including diabetes, hypertension, wound healing, antiseptics, and several types of cancer. Furthermore, silver nanoparticle-based products are intended to serve as diagnostic kits, dentistry, toothpaste, wound healing cream, shampoo, hair-care products, contact lenses, and other low-cost and economically cheaper items with outstanding results. Although many goods are yet ready to be launched for diverse applications, silver nanoparticles can be more efficient and easily accessible compared to other nano products.

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Conflict of interest

The authors declare that no competing interest

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