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Silver Nanoparticle as a Modern Era in Antimicrobial Activity

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A B S T R A C T

In the modern era of antimicrobial research, silver nanoparticles (AgNPs) have emerged as promising agents with unprecedented potential. This abstract encapsulates the multifaceted role of silver nanoparticles in combating microbial threats. AgNPs exhibit unique physicochemical properties that contribute to their antimicrobial efficacy, including a high surface area-to-volume ratio and distinct electronic and optical behaviours. These characteristics enable diverse antimicrobial mechanisms, such as disrupting cell membranes, interfering with cellular processes, and inducing oxidative stress. Moreover, the size-dependent activities of AgNPs enhance their specificity against a broad spectrum of microorganisms, including bacteria, fungi, and viruses. The abstract delves into the diverse applications of silver nanoparticles in various fields, from healthcare to environmental protection. AgNPs have found utility in medical devices, wound dressings, and pharmaceutical formulations, showcasing their versatility in preventing and treating infections. Additionally, the abstract emphasizes the role of silver nanoparticles in water treatment and disinfection, underscoring their potential impact on public health. However, challenges such as cytotoxicity and environmental concerns warrant meticulous investigation and optimization in the design and application of AgNPs. The abstract concludes by acknowledging the imperative nature of ongoing research in unraveling the full potential of silver nanoparticles as a modern-era antimicrobial strategy, offering unprecedented solutions to combat the evolving challenges posed by microbial resistance in the contemporary world.

Keywords:-Silver nanoparticles, Antimicrobial, Disinfection, Meticulous, Combat.

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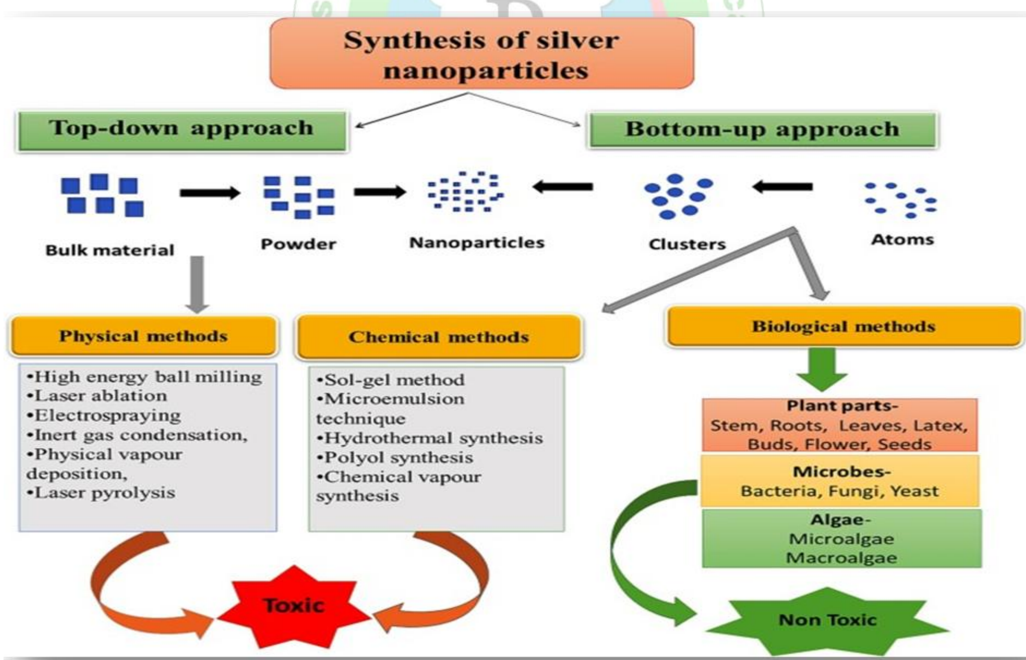
INTRODUCTION

Silver in all its forms has been historically used as an antimicrobial agent by itself or combined with other technologies [1] AgNPs are defined as a nanomaterial with all its dimensions in the range of 1–100 nm. These have shown superior capability and higher surface (area-to-volume ratio) compared to silver in its bulk form. At the nanoscale, this material exhibitions exceptional electrical, optical, and catalytic properties, which has led to the investigation and fabrication of products for targeted drug delivery, diagnosis, revealing, and imaging [2]. However, it is the extraordinary antibacterial activity exhibited by AgNPs that has focused the consideration of researchers and industries on this nonmaterial. AgNPs have shown antimicrobial activity against a variety of infectious and pathogenic microorganisms, including multidrug-resistant bacteria [3]. In order to fulfil the requirement of AgNPs, various methods have been adopted for synthesis. Generally, conventional physical and chemical methods seem to be very expensive and hazardous [4]. Interestingly, biologically-prepared Ag NPs show high yield, solubility, and high stability [5] among several synthetic methods for AgNPs, biological methods seem to be simple, rapid, non-toxic, dependable, and green approaches that can produce well-defined size and morphology under optimized situations for translational research. In the end, a green chemistry approach for the synthesis of AgNPs shows much ability.

Synthesis methods:-

Many routes have been introduced for the synthesis of silver nanostructures, which can be categorized as:

1. Chemical method
2. Physical method
3. Biological method



1.

Chemical Synthesis:-

Chemical Reduction Method:- Involves the reduction of a silver salt (e.g., silver nitrate) by a chemical reducing agent (e.g., sodium borohydride, citrate, or hydrazine) in the presence of a stabilizing agent (e.g., polyvinylpyrrolidone, sodium dodecyl sulfate). The reaction typically occurs in an aqueous solution and is performed at room temperature. [6,7]

Microemulsion Method:- Utilizes a microemulsion system consisting of water, oil, surfactant, and co-surfactant. The silver precursor is added to the microemulsion,

followed by a reducing agent. The confined environment of the microemulsion droplets allows for control over nanoparticle size and shape.[8]

Photochemical Synthesis:- Involves the use of light as the energy source to drive the reduction of silver ions. A photosensitizer is added to the silver ion solution, which absorbs light and generates reactive species that reduce silver ions to form nanoparticles.[9]

2. Physical Synthesis:-

Sputtering:- In this method, silver atoms are ejected from a solid silver target using an energetic particle beam (e.g., ions or electrons). The ejected atoms condense on a substrate to form a thin film, which can be further processed into nanoparticles using techniques like annealing or physical vapor deposition.[10]

Evaporation-Condensation:- Silver nanoparticles can be formed by evaporating silver in a vacuum, leading to the formation of vaporized silver atoms. These atoms subsequently condense on a substrate, where they aggregate and form nanoparticles.[11]

Laser Ablation:- Involves the use of a high-energy laser to ablate a solid silver target immersed in a liquid medium. The laser energy vaporizes the target material, producing a plasma plume containing silver ions and atoms. These species undergo nucleation and growth to form nanoparticles in the liquid medium.[12]

3. Biological Synthesis:-

Plant-Mediated Synthesis:- Utilizes plant extracts containing various phytochemicals (e.g., flavonoids, polyphenols) with reducing and stabilizing properties. These phytochemicals reduce silver ions to form nanoparticles in a biocompatible and eco-friendly manner.[13]

Microbial Synthesis:- Involves the use of microorganisms such as bacteria, fungi, and yeast to bioreduce silver ions into nanoparticles. Microorganisms produce enzymes and metabolites that act as reducing agents, facilitating the formation of nanoparticles. This method is environmentally friendly and offers control over nanoparticle size and shape.[14]

Each synthesis method has its advantages and limitations, and the choice depends on factors such as desired nanoparticle properties, scalability, cost, and environmental considerations.[15]

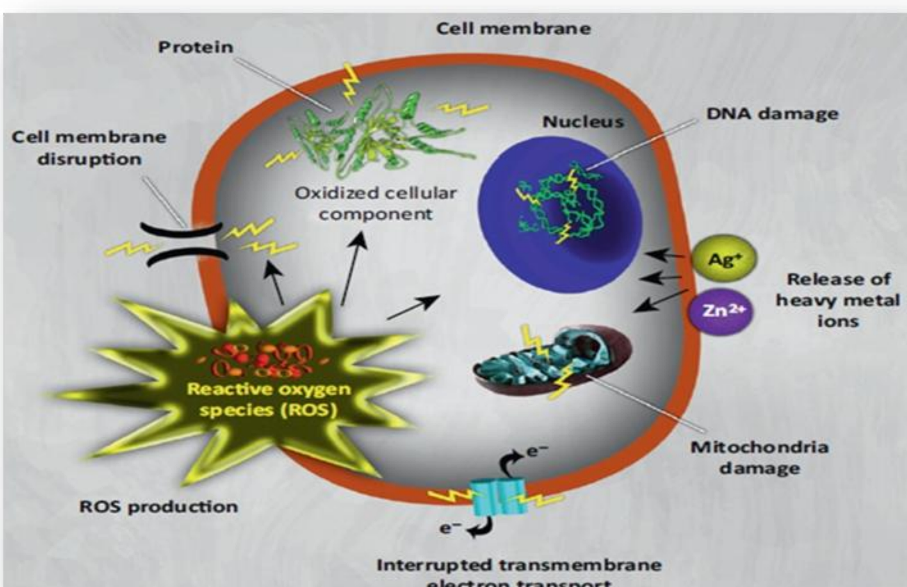
Properties of Silver nanoparticles:-

Physical and chemical properties of AgNPs—

Including surface chemistry, size, size distribution, shape, particle morphology, particle configuration, coating/capping, agglomeration, dissolution rate, particle reactivity in solution, efficacy of ion discharge, cell type, and finally type of decreasing agents used for synthesis—are crucial factors for determination of cytotoxicity [16,17]. For example, using biological reducing agents such as culture supernatants of several Bacillus species, AgNPs can be synthesized in some shapes, for example sphere-shaped, rod, octagonal, hexagonal, triangle, flower-like, and so on (Figure 2). Previous studies supported the assertion that smaller size particles could cause more toxicity than larger, because they have larger surface area [18]. Shape is equally important to the determination of toxicity.[19]

For example, in the biomedical field, various types of nanostructures have been used, including nanotubes, nameplates, Nano rods, spherical nanoparticles, flower-like, and so on [20]. Gap toxicity mainly depends on the availability of chemical and or biological coatings on the nanoparticle surface. Gap surface charges could determine the toxicity effect in cells. For example, the positive surface charge of these NPs renders them further suitable, allowing them to stay for a long time in blood stream compared to negatively-charged NPs, which is a major route for the administration of anticancer agents [21].

Mechanism of antimicrobial action: -



Silver nanoparticles (AgNPs) exhibit various mechanisms of action, making them effective in a wide range of applications.

1. Antimicrobial Activity:- AgNPs possess potent antimicrobial properties due to their ability to interact with microbial cells. They can disrupt microbial membranes, leading to increased permeability and leakage of cellular contents. AgNPs can also penetrate microbial cells and interfere with essential cellular processes such as DNA replication and protein synthesis, ultimately leading to cell death. This antimicrobial activity makes AgNPs valuable in applications such as wound dressings, coatings for medical devices, and water purification systems.[22,23]

2. Antioxidant Activity:- AgNPs have been shown to exhibit antioxidant properties by scavenging free radicals and reactive oxygen species (ROS). By neutralizing these harmful species, AgNPs can protect cells and tissues from oxidative damage, which is implicated in various diseases including cancer, neurodegenerative disorders, and aging.[24]

3. Anti-inflammatory Activity:- AgNPs have been reported to modulate inflammatory responses by inhibiting the production of pro-inflammatory cytokines and chemokines. This anti-inflammatory activity can help alleviate inflammation-associated conditions such as arthritis, asthma, and inflammatory bowel disease.[25]

4. Wound Healing:- AgNPs promote wound healing by accelerating the proliferation and migration of fibroblasts and keratinocytes, which are essential for tissue regeneration. Additionally, AgNPs exhibit antimicrobial activity, preventing wound infections and promoting a sterile environment conducive to healing.[26]

5. Drug Delivery:- AgNPs can serve as carriers for drug delivery due to their high surface area and ability to encapsulate or conjugate with therapeutic agents. They can facilitate targeted delivery of drugs to specific tissues or cells, enhancing therapeutic efficacy and reducing systemic side effects.[27]

6. Catalytic Activity:- AgNPs exhibit catalytic activity in various chemical reactions, including reduction, oxidation, and hydrogenation reactions. This catalytic activity can be utilized in environmental remediation, chemical synthesis, and energy conversion processes.[28]

7. Diagnostic Applications:- AgNPs can be functionalized with biomolecules such as antibodies, DNA probes, or aptamers to enable sensitive and specific detection of biomolecular targets. They are used in diagnostic techniques such as surface-enhanced Raman spectroscopy (SERS), lateral flow assays, and biosensors.[29]

Size dependent activity:-

Silver nanoparticles (AgNPs) have shown size-dependent activity in antimicrobials [30]. The size of AgNPs has been found to affect their antibacterial properties, with smaller nanoparticles exhibiting higher antimicrobial activity [31]. Studies have shown that AgNPs with sizes less than 100 nm have unique properties such as optical, catalytic, and electromagnetic properties, which are dependent on their size, shape, and surface Plasmonresonance.[32] The synthesis of AgNPs with different sizes has been investigated, and it has been observed that the size of AgNPs can be tuned based on the type of support used during synthesis.[33] The antimicrobial activity of AgNPs has been tested against various bacteria and fungi, including multi-drug-resistant bacteria and Candida albinos, and has been found to be effective in inhibiting their growth. The high bactericidal effect of AgNPs has been observed against different microorganisms, including Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa, Micrococcuslutes, Agrobacterium tumefaction's.[34]

Toxicological Study:-

Silver nanoparticles (AgNPs) have been broadly studied for their antimicrobial things. Several studies have investigated the toxicological aspects of AgNPs in relation to their antimicrobial activity. Chitosan-coupled silver nanoparticles were found to be non-toxic to mammalian cells and showed efficacy in wound healing [35]. The pharmacokinetic profile of AgNPs demonstrated enhanced dispersion throughout the body, indicating their potential for systemic antimicrobial effects [36]. Azoimidazole-conjugated AgNPs exhibited improved antimicrobial activity against various microorganisms, including bacteria, with concentrations below their individual minimal inhibitory concentration (MIC) [37]. The size and shape of AgNPs play a crucial role in their interaction with bacterial cells, leading to cell membrane disruption and subsequent cell death. Chitosan-based AgNPs synthesized using different concentrations of silver nitrate showed effective antibacterial and antifungal activity, making them suitable for wound dressing materials. Overall, these studies highlight the potential of AgNPs as antimicrobial agents, while also considering their toxicological effects.[38]

Application in Healtcare:-

Silver nanoparticles (AgNPs) have shown potential for application in healthcare as antimicrobial agents. AgNPs have been found to exhibit broad-spectrum antibacterial activity, including against multidrug-resistant bacteria. Various studies have explored the synthesis and characterization of AgNPs and their effectiveness against different pathogens. Chitosan-coupled AgNPs were synthesized and found to inhibit the growth of clinical pathogens and promote wound healing. AgNPs hybrids using organic and inorganic supports, such as sulfated cellulose nanocrystal, reduced graphene oxide, and titanium dioxide, were also effective in combating multi-drug-resistant bacteria and Candida albicans [39]. AgNPs synthesized using Gum Arabic extracts showed antimicrobial activity against Streptococcus sanguinis, Streptococcus mutans, Lactobacillus acidophilus, and Candida albicans, suggesting their potential use in dental healthcare [39]. Cotton fabrics coated with AgNPs using chitosan and chitosan-organosilica solutions demonstrated good stability and long-term antimicrobial activity, making them suitable for healthcare wearable textiles. The characteristics of AgNPs make them suitable for medical and healthcare products, where they can effectively treat or prevent infections.

Future perspective and challenges:-

Silver nanoparticles (AgNPs) have shown promising antimicrobial effects and are being explored for their potential applications in the field of antimicrobials. AgNPs have been synthesized using various methods, including green synthesis using plant extracts [40]. These nanoparticles have demonstrated effective growth inhibition against microorganisms such as Escherichia coli, yeast, and Staphylococcus aureus [41]. The use of AgNPs in antimicrobial control systems and medical devices has been suggested due to their ability to inhibit microbial growth. Additionally, nanoionics, which utilize nanomaterials for the management of bacterial diseases, have emerged as a promising approach in the field of antimicrobials [42]. However, further research is needed to optimize the synthesis parameters, concentration, and potential risks associated with the use of AgNPs in biomedical applications and intestinal environments. Despite the challenges, nanotechnology and nanoionics offer exciting opportunities for the development of effective antimicrobial strategies.

CONCLUSION:-

Silver nanoparticles have emerged as a modern era in antimicrobials due to their wide spectrum of antimicrobial and antifungal activity. They have been shown to be effective against both Gram-negative and Gram-positive bacteria, including multidrug-resistant strains. The unique physical and chemical properties of silver nanoparticles make them suitable for use in medical and healthcare products to treat and prevent infections. In addition to their antimicrobial properties, silver nanoparticles have also been investigated for their potential use in cancer therapy and radiotherapy. The broad-spectrum antibacterial activity of silver has been known for a long time, and silver nanoparticles show enhanced antibacterial activity. The synthesis of silver nanoparticles on different supports has been shown to provide effective antibacterial activity against clinically relevant multi-drug-resistant bacteria. Overall, silver nanoparticles offer a promising alternative for the treatment of infections and have the potential to revolutionize antimicrobial therapy in the modern era.

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