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A Review on Physical and Chemical Properties of Silver Nanoparticles

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مراجعة للخصائص الفيزيائية والكيميائية لجسيمات الفضة النانوية

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Abstract
Due to their excellent properties, silver nanoparticles (NPs) have garnered a lot of interest lately as highly desirable nanomaterials in research. They have a reputation for their strong antibacterial qualities, which can help fight off a variety of ailments. Their unique optical properties, like their limited SPR, make them more useful, especially in the imaging and biosensing domains. Furthermore, enhanced durability and targeted interactions with biological systems are provided by the capacity to modify them utilizing biocompatible chemicals and change their surface charge. Silver nanoparticles are perfect for several kinds of biological applications because of their remarkable durability and low chemical reactivity. Chemical, biological, and physical processes—all of which have unique benefits and drawbacks—produce these NPs. Complex purification, reactive components, and high energy consumption are common problems in chemical and physical processes. Although biological methods take longer to process, they are more environmentally friendly. The chosen synthesis method has a major influence on the stability, size distribution, and purity of the NPs. This review highlights how crucial it is to select the right synthesis technique in order to maximize the properties and applications of silver nanoparticles.**Keywords:** Silver nanoparticles, Optical properties, antimicrobial agents, Reproduction, Surface plasmon resonance, Physical and Chemical Properties

الخلاصة
نظرًا لخصائصها الممتازة، فقد اكتسبت جسيمات الفضة النانوية (NPs) الكثير من الاهتمام مؤخرًا باعتبارها مواد نانوية مرغوبة للغاية في الأبحاث. لديهم سمعة طيبة لخصائصهم المضادة للبكتيريا القوية، والتي يمكن أن تساعد في مكافحة مجموعة متنوعة من الأمراض. إن خصائصها البصرية الفريدة، مثل مواردها الخاصة المحدودة، تجعلها أكثر فائدة، خاصة في مجالات التصوير والاستشعار الحيوي. علاوة على ذلك، يتم توفير المتانة المعززة والتفاعلات المستهدفة مع الأنظمة البيولوجية من خلال القدرة على تعديلها باستخدام مواد كيميائية متوافقة حيوياً وتغيير شحنتها السطحية. تعتبر الجسيمات النانوية الفضية مثالية لعدة أنواع من التطبيقات البيولوجية بسبب متانتها الرائعة وتفاعلها الكيميائي المنخفض. العمليات الكيميائية والبيولوجية والفيزيائية – ولكل منها فوائد وعيوب فريدة – تنتج هذه NPs. تعد عمليات التنقية المعقدة والمكونات التفاعلية والاستهلاك العالي للطاقة من المشكلات الشائعة في العمليات الكيميائية والفيزيائية. على الرغم من أن الطرق البيولوجية تستغرق وقتا أطول للمعالجة، إلا أنها أكثر ملاءمة للبيئة. طريقة التوليف المختارة لها تأثير كبير على الاستقرار، وتوزيع الحجم، ونقاء NPs. تسلط هذه المراجعة الضوء على مدى أهمية اختيار تقنية التوليف الصحيحة من أجل تعظيم خصائص وتطبيقات جسيمات الفضة النانوية.

Introduction

Nanoparticles (NPs) are small materials that range in size from 1 to 100 nm. In addition to biological considerations, they offer unique chemical and physical properties, and their application has expanded across numerous industries. Their diminutive size and high surface-area-to-volume ratio set them apart from their larger counterparts (Eker et al., 2024). The release of silver ions that can interact with microbial membranes to disrupt cellular function and produce reactive oxygen species (ROS) is one of the primary mechanisms of silver nanoparticles' antibacterial effect, however this has not been fully demonstrated yet (Bamal et al., 2021). According to these several proposed mechanisms, silver nanoparticles are effective against a range of illnesses, including those that are resistant to multiple medications and antibiotics (Al-Mashhadani, et.al.,2024, Wang , L., et.al.,2017). Similarly, several applications also draw attention to these systems. For instance, antimicrobial activity is crucial for dental, wound-healing, and agricultural uses. Bapat et al. (2018), Terra et al. (2019), and Paladini et al. (2019). Additionally, for bioimaging and anticancer applications, the intracellular activity, membrane penetration, and silver ion release of silver nanoparticles are crucial (Haque et al., 2021). However, the wide range of applications for silver nanoparticles is greatly influenced by their manufacturing process. In other words, these components are crucial for controlling silver nanoparticle applications. Because of their great electrical and thermal conductivity, silver nanoparticles have found application in electronics, where they can be found in conductive inks, adhesives, and electronic components. Because of their efficient heat conduction, they are also utilized in energy storage devices and for thermal management (Kalidasan, et.al.,2023). Additionally, the conductivity and other outstanding optical properties of silver nanoparticles are due to the localized surface plasmon resonance (LSPR) phenomenon. This action is brought on by the resonance of conduction electrons on the NP surface with incident light, which gives silver NPs strong absorbance and scattering properties. They are therefore highlighted as potential materials for photothermal, biosensing, and bioimaging treatments (Farooq et al., 2018). They can also boost the sensitivity of surface-enhanced Raman scattering (SERS) due to their LSPR characteristics. SERS is useful for environmental monitoring and medical diagnostics since it can detect low analyte concentrations (Ravindran et al., 2013) .This modification can expand the NPs' utility in the biomedical field by improving their stability, biocompatibility, and target selectivity (Hoang et al., 2020). The physicochemical characteristics of silver nanoparticles have attracted a lot of attention, especially in biological applications. Numerous techniques, such as chemical, biological, and physical processes, are used to create silver nanoparticles (Al-Mashhadani et al., 2023; Dhaka et al., 2023). Among the characteristics that are directly influenced by the chosen synthesis method are the stability, purity, and size distribution of NPs. Despite their effectiveness, hazardous reactants can be used in standard chemical and physical processes.They can also be hazardous to the environment, have low conversion efficiency, need a lot of energy and money, and have challenging purifying processes. On the other hand, NP synthesis can be done in an environmentally benign way by using bio-based synthesis methods, which use microbes, plants, or algae. By acting as efficient stabilizing and reducing agents, these organisms eliminate the need for dangerous chemicals. Furthermore, due to the presence of natural capping agents such proteins and polysaccharides, silver nanoparticles made by biological synthesis exhibit exceptional colloidal stability. These substances enhance the dispersion of silver nanoparticles in water-based solutions and inhibit agglomeration. The presence of naturally occurring bioactive chemicals on their surfaces can result in enhanced or combination antibacterial properties, in addition to the features of the production process. due biological methods use renewable resources like plant extracts or microbe cultures, they are cost-effective; but, due of batch-to-batch homogeneity and material variability, scaling them up can be challenging. They do, however, have some disadvantages, including the need for meticulous culture management and longer processing times (Mustafa, et.al.,2020). For generating NPs, top-down and bottom-up approaches are commonly employed. NPs are created by atomic and molecule assembly in bottom-up synthesis techniques such chemical vapor deposition and bio-based synthesis. A potential method for cost-effective and non-toxic synthesis is presented here. It is essential to select the technique that best combines the benefits and limitations in order to produce NPswith the necessary properties Iqbal, *et.al.,*2012 ,Abid, *et.al.,*2022. NPs have become one of the most researched materials in science at the moment. More than 500,000 published documents, including articles and patents, were reported in the last five years, according to statistics from the Web of Science Core Collection (Al-Mashhadani, *et.al.,*2024). In particular, 54.070 of these documents—or 10% of all published papers in the subject of nanomaterials—deal with silver nanoparticles. Researchers assessed different manufacturing techniques, antibacterial qualities, drug delivery system development, and toxicological consequences in recent publications pertaining to silver nanoparticles. The green-synthesised methods were one of the main areas of emphasis, in an effort to lessen the negative effects of silver nanoparticles. Therefore, taking into account these recent studies and impressive statistics, our goal is to address the current developments with silver NPs in order to contribute to NP research with a thorough assessment. This article discusses the antibacterial effects and enhanced optical qualities of silver nanoparticles, which have been the subject of recent works evaluating different production processes, antimicrobial properties, medication delivery system development, and sociolegal domains. The ways by which silver nanoparticles advance nanotechnology are thoroughly examined in the work. The primary synthesis methods are also examined, along with the specific physical and chemical characteristics of silver nanoparticles and instances of their current applications. The application areas, advantages, and disadvantages of NP synthesis techniques—which are divided into three main categories—are thoroughly examined in this article. Exemplary instances are provided to enable thorough analysis. The main and distinctive feature of this research is its thorough analysis of patent patterns related to silver nanoparticles, The proportion of patents with keywords pertaining to "synthesis methods" and physical and chemical attributes compared to

all patents published between 2019 and 2024 Figure-1. The same is true for silver nanoparticles' antibacterial applications, since the majority of silver NP-based applications are based on their antimicrobial qualities. Silver nanoparticles are increasingly being used in hybrid materials, including nanocomposites or complexes, especially with polymers, for antibacterial, wound-healing, and drug delivery applications. These hybrid materials are favored due to their capacity to lower possible cytotoxicity in addition to their increased efficiency. Based on current research, this article has discussed the aspects influencing these uses on a wide scale. It has also outlined a roadmap for the future of this sector, highlighting the significance of the properties and production processes of silver nanoparticles. This article concludes by discussing the many facets of silver nanoparticles and their significance in a number of domains, including their enhanced optical properties and antibacterial effects. The ways by which silver nanoparticles advance nanotechnology are thoroughly examined in the work. The primary synthesis methods are also examined, along with the specific physical and chemical characteristics of silver nanoparticles and instances of their current applications. The application areas, advantages, and disadvantages of NP synthesis techniques—which are divided into three main categories—are thoroughly examined in this article. Exemplary instances are provided to enable thorough analysis. The main and distinctive feature of this work is its thorough analysis of patent trends related to silver nanoparticles, with a focus on synthesis methods and material properties. This article presents a thorough overview of silver nanoparticle research and potential applications, with a focus on synthesis and patent trends (Al-Mashhadani, *et.al.,*2022). The article highlights the growing potential for ecologically friendly industrial uses and suggests significant developments in this field, indicating a growing interest in green commercialization strategies.

2. Properties of Silver Nanoparticles

Because of their small size and high surface-area-to-volume ratio, silver nanoparticles (NPs) have unique physical and chemical properties that represent typical NP attributes . Their shape, size, surface chemistry, content, coating, and aggregation all have a major role in these attributes, which also include strong electrical and thermal conductivity, antibacterial activity, and optical qualities (Zhang, *et.al.,* 2016). Accordingly, the production process is equally crucial for determining the properties ofsilver nanoparticles. For example, a recent review illustrated the benefits and drawbacks of silver NP synthesis techniques using physical, chemical, and biological methodologies.Furthermore, silver nanoparticles (NPs) have stable and less reactive chemical properties than other metals (Zhang, *et.al.,* 2022). These characteristics make them exceptional agents for a wide range of biological applications, such as cancer therapy, diabetes treatment, wound healing, biosensors, bioimaging, and antibacterial coatings (Burdus, *et.al.,*2018).The toxicity potential of silver nanoparticles is also connected to their properties, and this topic has been covered in great detail in the literature as of late (Jaswal, *et.al.,*2023). However, the toxicity section will go into great depth about these adverse effects, including their causes and possible health hazards. We have examined the numerous characteristics of silver nanoparticles and their importance across a range of fields in this section. Silver nanoparticles have been included into numerous cutting-edge studies and applications due to their remarkable antibacterial properties and improved optical characteristics (Galatage, *et.al.,*2021). The present state of research, this section attempts to give readers a thorough grasp of how silver nanoparticles, with their special properties, contribute to advancements in nanotechnology.

Figure.1: Ag NPs solution

2.1 Size One of the key elements influencing the physical, chemical, and biological characteristics of silver nanoparticles is their size (Almatroudi, *et.al.,*2020). It has a major impact on their conductivity, optical properties, and surface-area-to-volume ratio in addition to opening doors in a number of other areas (Natsuki, *et.al.,*2015). In solution or on surfaces, their tiny size enhances their reactivity and interaction with the surrounding molecules (Kim, *et.al.,*2012). Because of their size-dependent surface characteristics, silver nanoparticles (NPs) are used as catalysts in catalysis and sensing research, where their enhanced reactivity is particularly beneficial (Shenashen, *et.al.,* 2014). Nanoparticles may additionally be employed for targeted medication delivery and imaging in biomedical applications because of their small size, which also makes it easier for them to enter biological systems (Sironmani, A., & Daniel, K., 2011). However, their high penetration effectiveness may also lead to elevated toxicity, suggesting that the size of silver nanoparticles and their toxicity are related. Additionally, Cho et al. found that smaller silver nanoparticles (about 10 nm in diameter) had more hepatotoxic effects in mouse models than their bigger counterparts (60 and 100 nm) Figure-2 (Cho, *et.al.,*2018). Taking these into account, it is clear that NPs' size has a significant impact on their toxicity, biological impacts, and physical characteristics. Size must therefore be carefully considered during the synthesis process.

Figure.2: Photographs of the samples prepared different concentrations of Ag colloids

2.2. Shape Spherical, rod-shaped, triangular, cubic, wire-like, and star-shaped silver nanoparticles can all be created (Zhang, *et.al.,*2022). The form of the silver nanoparticles affects a variety of properties, including optical, catalytic, and electrical (Natsuki, *et.al.,*2015). For example, the silver nanoparticles' size and structure greatly enhance their interactions with biological systems. They can therefore be used in the biomedical field, particularly in coatings and drug delivery systems Taheri, *et.al.,*2014 and Todorova, *et.al.,*2023. Moreover, the rate at which silver ions are released from silver nanoparticles may have an impact on the antibacterial activity. In this way, spherical nanoparticles (NPs) are preferred because they can release silver ions more effectively than other shapes like triangular plates and disks because of their larger surface-area-to-volume ratio. By enabling a more efficient rupture of bacterial cell membranes and interference with cellular functions, this enhanced ion release amplifies the antibacterial action of silver nanoparticles (Cheon, *et.al.,*2019). Because of their exceptional antibacterial qualities, ease of synthesis, and homogeneity, spherical silver nanoparticles are therefore typically chosen for application in biomedical settings. Nevertheless, triangular-shaped silver nanoparticles have also drawn interest due to their unique antibacterial qualities, which have been thoroughly investigated and contrasted with those of their spherical counterparts (Raza, et.al.,2016). Additionally, the electrochemical behavior of silver nanoparticles (NPs) in alkaline solutions was examined in a variety of geometries, including nanospheres, nanocubes, and nanoprisms. Results indicated that, in contrast to nanospheres and nanocubes, nanoprisms increased catalytic activity. The findings emphasize how important shape-dependent electrochemical characteristics are, particularly in fuel cell and sensing applications (Bansal, et.al.,2010). Additional a different study contrasted the skin permeability of silver nanoparticles in three different shapes: spherical, rod-shaped, and triangular. When compared to other forms, rod-shaped silver nanoparticles were found to have the highest permeability. Because rod-shaped silver nanoparticles accumulated the greatest in the circulation following topical treatment, these results were also shown in in vivo mouse tests (Tak, et.al.,2015). In conclusion, because the shape of silver nanoparticles affects their properties, certain shapes provide special benefits such improved antibacterial effectiveness, catalytic activity, penetrating ability, and optical qualities (Amirjani, et.al.,2019). The shape during the synthesis process can therefore improve the use of silver nanoparticles in a variety of applications.

.٢،٣Surface Charge

One of the crucial characteristics of NPs that has a big impact on their stability and interactions with other molecules is their surface charge. The behavior of NPs in various settings can be precisely controlled by adjusting the surface charge, which affects their reactivity, solubility, and aggregation. Accordingly, the surface charge is also thought to be crucial in biomedical applications, where altered surface charges enhance treatment efficacy, targeting, and absorption (Fröhlich, 2012). Additionally, surface functionalization and pH changes can be used to control surface charges. All things considered, these charges affect how they interact with other biomolecules or surfaces as well as how they disperse in matrices or solvents (Qiao, et.al.,2019). As an example, it has been demonstrated that electrostatic repulsion improves the dispersion of positively charged silver nanoparticles in aqueous solutions when they have fully functionalized with polymers (polyethyleneimine or chitosan) Liu, et.al.,2014 and Kumar-Krishnan, et.al.,2015). Furthermore, altering surface charges affects how silver nanoparticles behave biologically. For instance, Abbas et al. looked into how various surface charges on silver nanoparticles (NPs) impact their capacity to fight off germs like Escherichia coli (E. coli) and Staphylococcus aureus (S. aureus). Results showed that, in comparison to their neutral and negatively charged counterparts, positively charged silver nanoparticles were the most bactericidal, forming wider zones of inhibition and needing lower concentrations to be effective (Abbaszadegan, et.al.,2015). In a similar vein, El Badawy et al. investigated how surface charges affected the toxicity of silver nanoparticles to Bacillus species. They showed a correlation between surface charges and toxicity, concentrating on silver nanoparticles with different surface charges (positive, negative, and neutral). Because they had a major impact on bacterial oxygen consumption and cell viability, positively charged silver nanoparticles in particular were the most lethal of their counterparts (El Badawy, et.al.,2011). In brief, the stability, dispersion, and reactivity of silver nanoparticles are significantly impacted by surface charge modulation. Therefore, it might be regarded as a successful strategy to maximize their use in biomedical applications.

.٢،٤ Melting Point and Electrical Conductivity

Compared to other metals, silver has some of the highest electrical conductivity at room temperature due to its atomic structure and the existence of free electrons (Kockert et al., 2019). Like other metals, silver has a single valence electron in its outermost shell that is tangentially connected to the nucleus. Consequently, it allows free electron mobility between the metals, allowing a conductive channel. In other words, when an electric field is present, these electrons will be free to move, enabling the electric current to pass without encountering any obstacles. These free electron movements are primarily responsible for silver's electrical conductivity and application in conductive composite compositions with both organic and inorganic materials (Varga et al., 2012). Since there's a strong electrostatic repulsion between particles that inhibits agglomeration at higher values (both at negative and positive values), zeta potential is a crucial indicator of stability (Syafiuddin, et.al.,2017). Because silver nanoparticles are smaller than their bulkier counterparts, they have lower melting points, which is favorable . More specifically, when particles get smaller, the surface area to volume ratio rises, increasing the amount of free energy on the particle's surface. For applications like nanocomposite materials for sophisticated electrical devices and sensors, which need high melting temperatures, this feature makes lower temperature techniques possible and enhances practicality. Silver nanoparticles' slightly lower melting point offers a great deal of promise for electrical research because it can improve the sintering process, which fuses particles to form cohesive structures. By creating continuous conductive channels at lower temperatures, this technique enhances electrical performance, making it beneficial for high-frequency electronic applications (Alshehri et al., 2012).

.٢،٥ Conductivity of Heat

It is commonly known that silver has an extraordinary thermal conductivity of about 429 W/mK at ambient temperature. Because of this property, silver transfers heat easily (Zhou et al., 2018). Silver nanoparticles offer exceptional heat conductivity due to their high surface-area-to-volume ratio, which remains constant even at the nanoscale (Iyahraja et al., 2015). The main reason for the high thermal conductivity is the effective transfer of heat by phonons and electrons, which is made possible by the small size of the particles. At the grain boundaries, this lessens dispersion and resistance (Wu et al., 2014). Because of their lower sintering temperatures, silver nanoparticles (NPs) provide enhanced thermal conductivity, decreased oxidative resistance, and reduced contact resistance, making them ideal for a range of technological and industrial applications (Sun et al., 2022). For example, Li et al. showed how well silver nanoparticles work to improve LED device temperature regulation. Silver nanoparticles (NPs) were added to thermal interface materials to improve heat dissipation and decrease thermal resistance in order to improve LED performance and operational longevity

(Li, J., et.al., 2021). Ultimately, silver nanoparticles are very interesting tools for enhancing heat management in next research because of their exceptional thermal conductivity, robustness, and ease of manufacture.

.٢،٦Properties of Optics

Because of their unique optical characteristics, silver nanoparticles have been regarded as being particularly useful. Their LSPR, a phenomenon in which conduction electrons on the NP surface oscillate in resonance with incident light, is primarily linked to these characteristics (Nosheen, et.al.,2019). Light, usually in the visible spectrum, is strongly absorbed and scattered as a result of this phenomenon. As a result, the colors that silver nanoparticles exhibit might vary depending on their size, shape, and surrounding media. Additionally, LSPR produces stronger electromagnetic fields close to the NP surface. This facilitates the usage of silver nanoparticles in a variety of applications, such as biological sensing, imaging, and photothermal therapy, and renders them extremely sensitive to changes in the environment (Juma, et.al.,2024). Silver nanoparticles' enhanced sensitivity to refractive index is also crucial for their application in sensor technologies. They increase the measurement's precision by making it possible to detect changes in the surrounding medium more precisely. Additionally, this sensitivity can be greatly influenced by carefully adjusting the NPs' size, shape, and surface characteristics, which allows for performance optimization Martinsson, et.al.,2014). Additionally, using a method called SERS, silver nanoparticles are thought to be crucial in Raman spectroscopy. SERS, a very sensitive Raman spectroscopy method, greatly amplifies the Raman signals of molecules that have been adsorbed onto the surface of silver nanoparticles. In this way, even at pico- and femtomolar levels, it enables the detection of incredibly tiny quantities of Raman-active analytes (Krishna, et.al.,2016). Also, a correlation between the antibacterial efficacy of silver nanoparticles and their optical characteristics was demonstrated. Silver nanoparticles (NPs) with certain surface plasmon resonance properties, like narrow full width at half maximum and well-defined spherical shapes, have been shown by Mlalila et al. to be more effective against a variety of microorganisms, including bacterial strains like E. coli (Mlalila, et.al.,2016). In final analysis, silver nanoparticles' remarkable optical qualities, which are typified by their LSPR, produce unique light absorption and scattering features. These characteristics highlight silver nanoparticles' vital role in improving Raman spectroscopy via SERS in addition to making them appropriate for a variety of applications. Given these elements, silver nanoparticles are probably going to be unique in next studies and uses because of their exceptional qualities .

.٢،٧Activity Against

The bacteria the significant antibacterial activity of silver nanoparticles is influenced by a number of parameters, including size, shape, surface charge, and the release of silver ions. Because of their small size and large surface area, silver nanoparticles can interact with bacterial cell membranes, compromising their integrity, causing the contents of the cell to leak out, and ultimately resulting in cell death (Bruna et al., 2021). Even if the antibacterial action of silver nanoparticles has not been thoroughly demonstrated, the majority of the proposed mechanisms are mostly linked to the release of silver ions. These ions specifically disrupt the amine, phosphate, and thiol residues in proteins and enzymes, which results in cellular toxicity (Menichetti et al., 2023). These ions specifically disrupt the amine, phosphate, and thiol residues in proteins and enzymes, which results in cellular toxicity (Menichetti et al., 2023). Li et al. demonstrated in one study that the silver ions released by NPs form compounds with the thiol groups on bacterial membranes, disrupting protein structures and enzyme activity that are vital to bacterial viability. It was further asserted that this method disrupts the lipid-protein bonds in the bacterial cell membrane, allowing intracellular molecules to escape and endangering the cell's ability to maintain homeostasis and defend against outside stresses (Li et al., 2016). ROS, which is produced by silver ions, can lead to oxidative stress and harm cells' lipids, proteins, and DNA. Park et al. highlighted this by investigating the antibacterial qualities of the silver ions generated by silver nanoparticles and their ability to generate reactive oxygen species (ROS). Prior to evaluating the ROS levels, they specifically exposed both Gram-positive and Gram-negative bacteria to silver ions. The E. coli cell population under aerobic conditions decreased by 2.2 and 3.3 logs when 0.5 and 1.0 mg/L silver ions were administered, respectively. Anaerobic conditions were less efficient for the same concentrations, causing declines of 0.5 and 1.9 log. In addition to ion release, silver nanoparticles (NPs) have bactericidal effects by merely altering bacterial cell membranes. Their tiny size results in membrane denaturation and structural alterations when they build up in surface pits. As a result, they cause cell lysis and organelle disruption (Yin, et.al.,2020). Furthermore, protein phosphorylation is impacted by silver nanoparticles' interference with bacterial signal transduction pathways, which results in cell death and growth suppression (More, et.al.,2023). Together, these several mechanisms—which include interfering with cellular functions—emphasize the versatility and potency of silver nanoparticles as antimicrobial agents. As a result, they successfully combat a range of diseases, including common bacterial strains, including both Gram-positive and Gram-negative ones. Numerous applications make use of silver nanoparticles' capacity to target a wide range of diseases. For instance, silver nanoparticles are used in bone graft materials and implants to benefit from their dual benefits of antimicrobial activity and bone healing stimulation. When added to implant coatings or bone grafts, silver nanoparticles create an environment that is hostile to microorganisms, lowering the incidence of post-operative infections. Additionally, silver nanoparticles promote mineralization and osteoblast activity at the application site, which promotes bone regeneration (Nie et al., 2023). Because silver nanoparticles have potent antibiofilm and antibacterial qualities that can improve oral hygiene, their usage in dentistry is also growing. Their application in dental coatings and materials lowers the possibility of bacterial infections during dental procedures. As a result, they are seen as essential components to improve dental health (Bapat, et.al., 2018). Similarly, antimicrobial materials are essential for food packaging applications. Due to their strong antibacterial properties, silver nanoparticles are currently used as a packaging material in a variety of films and nanocomposites for food packaging applications (Istiqola et al., 2020).

Conclusion

The increasing popularity of silver nanoparticles emphasizes how important it is to completely understand their properties and production methods. These NPs' distinct physical and chemical characteristics are influenced by their size, shape, surface charge, and production process. Their small size and high surface area to volume give them unique properties include optical characteristics, antibacterial activity, and electrical and thermal conductivity. Additionally, these properties enable silver nanoparticles to discharge silver ions more efficiently, which breaks down bacterial membranes and boosts antibacterial effectiveness. The majority of studies indicates that small-sized silver nanoparticles are superior for these applications because of their improved cell viability and increased bactericidal activity. Particle size has a significant impact on how NPs are distributed in applications. For example, small-sized NPs are preferred in bioimaging applications due to their increased cellular accumulation and enhanced LSPR properties. However, larger NPs that exceed certain threshold values are more suited to control the particle mobility within the tissue in wound healing studies. Other common applications for silver nanoparticles are comparable. The exceptional efficacy of tiny silver nanoparticles in antibacterial studies has been highlighted by numerous studies. Size determination becomes more crucial if the NP is meant to be used for dual-treatment with other kinds of molecules or for the creation of nanocomposites. The stability and aggradation potential of silver nanoparticles are greatly influenced by their size, whether they are utilized singly or in combination. Given their significant potential in nanotechnology and compatibility with a variety of systems and nano molecules, it is clear that the size of silver nanoparticles should be carefully controlled during the production process .

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