WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Silver Nanotech: Sustainable Synthesis and Eco-Friendly Applications of Silver Nanoparticles

Bhanulekha. K [a], Farhani Irum JP [a], Dr. Vinutha. K [b]*

[a] M. Pharmacy Students Department of Pharmaceutical Quality Assurance at Sarojini Naidu Vanita Pharmacy Maha Vidyalaya Osmania University, Hyderabad, India, 500017

[b]*Assistant Professor Department of Pharmaceutical Quality Assurance at Sarojini Naidu Vanita Pharmacy Maha Vidyalaya Osmania University, Hyderabad, India, 500017

ABSTRACT

Over time, there has been a lot of interest in nanotechnology. Nanoparticles, which range in size from 1 to 100 nanometers, are made of metals, carbon, metal oxides, and organic materials. Because of their unique physical and chemical properties, silver nanoparticles (AgNPs) are becoming more and more common in a variety of industries, including consumer goods, food, healthcare, and medicine. When silver nanoparticles (AgNPs) interact with host or pathogenic cell proteins and enzymes, they cause the cells to die, exhibiting potent antimicrobial properties. Although there are several ways to make nanoparticles, chemical processes are the most widely used. Different techniques, classified as top-down or bottom-up approaches, are used to synthesize nanoparticles. Nanoparticles can be analysed using methods such as Fourier Transform Infrared (FT-IR) Spectroscopy, UV-Visible Spectroscopy, Transmission Electron Microscopy (TEM), and Scanning Electron Microscopy (SEM) to determine their potential and applications.

KEYWORDS**:** Nanoparticles, Antimicrobial, Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM)

INTRODUCTION:

Nanotechnology is an advanced field that allows for the precise manipulation and examination of structures and devices ranging from 1 to 100 nanometers in size, with remarkable accuracy and efficiency[1].

Nanomaterials are not simple molecules and their surface effects differ from those of micromaterials or bulk materials for three key reasons. Firstly, nanomaterials that are dispersed have a very large surface area and high particle number per mass unit. Secondly, there is an increase in the percentage of atoms present on the surface of nanomaterials. And thirdly, there is a decrease in the number of direct neighbours of atoms present on the surface of nanomaterials[2].

The peculiar physical and chemical attributes of silver nanoparticles (AgNPs) render them extensively adaptable in numerous domains like consumer merchandise, industry, sustenance production, and healthcare practices. These particles are incorporated into a multitude of commodities, acting as antimicrobial elements across home environments; sectors oriented toward manufacturing; plus realms linked to medical applications. Extra to these roles, they serve within the alimentary sector; drug-making industries; devices meant for sensing optically; everyday-use products and also in layers designated for sanitarian equipment. In medicinal zones particularly concerning delivery means for medication; orthopedic ventures and diagnostic procedures AgNPs assume a role. They potentially act against cancer-causing cells too. An intriguing observation discloses their potential to bolster anticancer drugs' capacity thwarting tumor growth significantly[3].

Although there exist several techniques for generating nanoparticles, chemical reactions are the most widely used method. Toxic compounds must be used in certain chemical methods, which can be dangerous. Platinum, silver, and other noble metal nanoparticles are frequently used in settings where human contact is possible. Another option is to create nanoparticles biologically by using microorganisms[4].

CLASSIFICATION OF NANOPARTICLES:

Nanoparticles fall into three main categories based on their composition: organic, carbon-based, and inorganic[2].

Organic based NPs:

This group comprises nanoparticles made from proteins, carbohydrates, lipids, polymers, or similar organic compounds. Examples include dendrimers, liposomes, micelles, and protein complexes like ferritin[2]. Generally, these nanoparticles exhibit characteristics such as non-toxicity, biodegradability, and, in cases like liposomes, they may have a hollow core. They are also sensitive to thermal and electromagnetic radiation, such as heat and light[5].

Carbon based NPs:

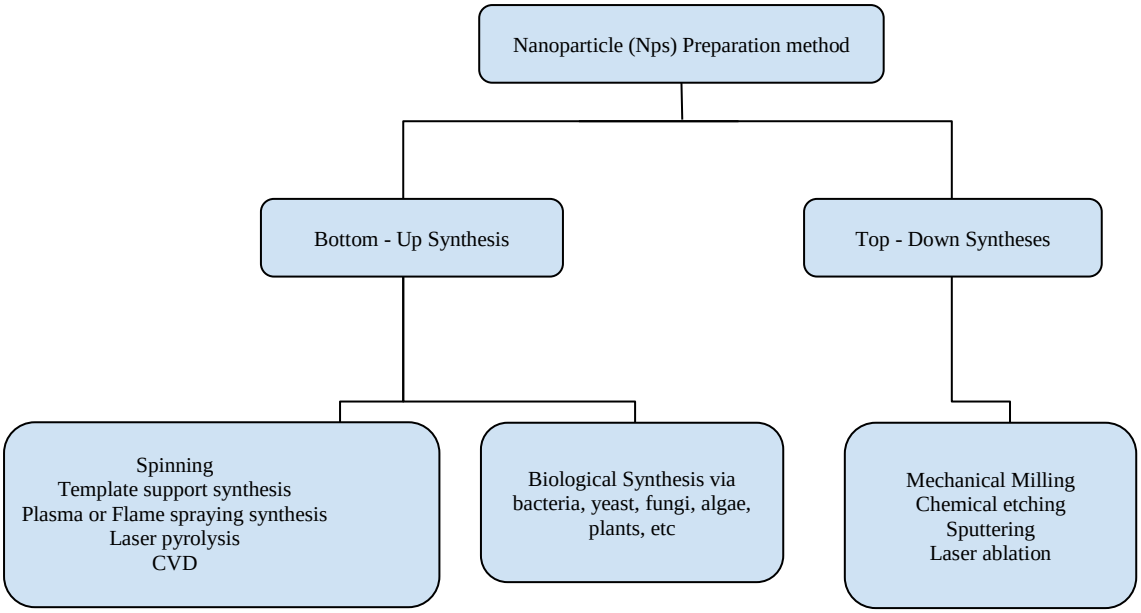
Nanoparticles that are made entirely of carbon are called carbon-based nanoparticles[5]. Some well-known examples of this type of nanoparticles are fullerenes, carbon black NPs, and carbon quantum dots. Fullerenes are special carbon molecules that have a symmetrical closed-cage structure. For example, C_{60} fullerenes consist of 60 carbon atoms that are arranged like a soccer ball. Moreover, there are other types of fullerenes, such as C_{70} and C_{540}, that have also been discovered[2].

Inorganic Based NPS:

Inorganic nanoparticles are particles that do not contain carbon. Metal and metal oxide-based nanoparticles fall under the category of inorganic nanoparticles. Metal nanoparticles are derived solely from metal precursors and can take the form of monometallic, bimetallic, or polymetallic structures. Their unique optical and electrical properties stem from their localised surface plasmon resonance characteristics. Additionally, specific metal nanoparticles exhibit distinct thermal, magnetic, and biological attributes[2].

TYPES OF SYNTHESIS:

Two main approaches exist for synthesising nanoparticles: bottom-up and top-down.



1. ***Bottom-up:***

The reverse approach of creating nanoparticles from simpler substances is known as the building-up approach. This can be achieved using techniques such as sedimentation and reduction, biochemical synthesis, sol-gel, green synthesis, and spinning. A recent example is the solvent-exchange method used by Needham et al. to produce limit-sized low-density lipoprotein (LDL) nanoparticles for medical cancer drug delivery. In this process, nucleation serves as the bottom-up approach followed by growth, constituting the upward progression. These LDL nanoparticles were obtained without the use of phospholipids and exhibited high hydrophobicity, which is a critical feature for drug delivery applications[6].

2. ***Top-down:***

This method involves breaking down larger molecules into smaller units, which are then transformed into nanoparticles. Methods such as grinding, chemical vapor deposition (CVD), physical vapor deposition (PVD), and other decomposition methods come under this category. For instance, a top-down method can be used to synthesize colloidal carbon spherical particles with precisely controlled sizes. The synthesis process involves the continuous chemical adsorption of polyoxometalates (POM) onto the carbon interfacial surface[6].

METHOD OF PREPARATION:

1. ***Physical method preparation:***

Using a "top-down" methodology, the physical method employs crushing, impacting, disrupting, degrading, cutting, cryogrinding, grinding, processing, and homogenization to break down bulk material into fine particulate matter. Physical methods such as refining, high-energy ball milling (HEBM), ball milling, grinding, and homogenization techniques like high process homogenization (HPH) and medium-pressure homogenization (UHPH) fragment microparticles during the milling process.While these physical techniques offer versatility in producing nanoparticles with controlled larger size, diameter, and volume, they may introduce surface defects, contamination, and entail high costs and time consumption. Although achieving nanoparticles of uniform size is feasible, the equipment setup is prohibitively expensive, with maintenance costs also posing significant challenges. These limitations have spurred interest in exploring biological sources and methods for nanoparticle manufacturing, particularly for space travel applications, given their efficiency and cost-effectiveness[7].

2. Chemical method preparation:

Chemical reduction with a range of organic and inorganic reducing agents is the main technique used to produce silver nanoparticles. Aqueous and non-aqueous solutions are used to employ these agents, which include ascorbate, Sodium Borohydride ($NaBH_4$), Sodium citrate, elemental hydrogen, Tollens reagent, N, N-dimethylformamide (DMF), and Poly ethylene glycol block polymers. These agents cause silver ions (Ag^+) to reduce to metallic silver (Ag0), which starts the process of forming metallic colloidal silver particles. These particles start as oligomeric clusters that eventually aggregate. To maintain the stability of the dispersed nanoparticles during synthesis, protective agents are essential. These agents, typically surfactants with functional groups like thiols, alcohols and acids, adsorb onto nanoparticle surfaces, preventing their agglomeration and preserving their surface properties[8].

3. Biological method preparation:

Biological synthesis involves creating nanoparticles using plant extracts, bacteria, and fungi.

Phytonanotechnology is a rapidly growing field that shows promise for synthesising nanoparticles in an environmentally friendly, straightforward, and cost-effective manner. One of the main advantages of this technology is that it allows for scalability and the use of water as a universal solvent for reducing agents, making it a biocompatible solution. Different parts of plants such as roots, stems, seeds, and leaves can be used for nanoparticle synthesis. However, the exact mechanism involved in this process is not yet fully understood. It has been observed that organic acids, proteins, and secondary metabolites such as alkaloids, flavonoids, polysaccharides, and heterocyclic compounds play a crucial role in synthesising various types of nanoparticles.

In the synthesis of nanoparticles, microorganisms provide a practical and affordable substitute for dangerous chemicals and high energy requirements by functioning as "nanofactories.". Additionally, this method is eco-friendly. Because they contain different reductase enzymes, which are necessary for the reduction of metal salts into nanoparticles, microorganisms are able to accumulate and detoxify heavy metals. A lot of research has been done recently on the ability of bacteria, fungus, and yeast to synthesize nanoparticles. Metal-resistant genes, proteins, reducing cofactors, enzymes, and organic materials are all important capping agents in the synthesis of nanoparticles[9].

CHARACTERIZATION:

1. UV visible Spectroscopy:

UV-Vis spectroscopy is vital for understanding the formation of silver nanoparticles during the initial synthesis stage.

UV-Vis absorption spectroscopy is a valuable technique for characterising absorbance bands and band gaps of nanoparticles, especially those made of noble metals. This is particularly true for diffuse reflectance spectroscopy (DRS), which enables the examination of nanoparticles optical properties. Noble metals are highly coloured and show absorptions that are caused by oscillations of surface plasmons. Light waves that are restricted to the surface as a result of their interaction with free electrons in the metal are known as surface plasmons. It is noteworthy that the spectrum of metal nanoparticles lacks the surface plasmon resonance (SPR) band, which is specific to these particles[10].

2. Transmission electron microscopy (TEM):

The use of transmission electron microscopy (TEM) in the characterization of nanoparticles is unquestionably essential. It creates micrographs of nanoscale materials with remarkable lateral spatial resolution by focusing an electron beam onto a thin sample, typically less than 200 nm thick. Additionally, by concentrating and containing the electron beam and examining the resulting electron diffraction pattern, TEM enables the study of the crystalline structure of particular microscopic regions within crystalline materials. This method makes it easier to examine the specific particle level characteristics of shape, size, and crystal structure. Even though it can provide a nanometer-level visual inspection of individual particles, the entire procedure—sample preparation, measurement, and analysis—can be very labor-intensive. In addition, TEM requires highly skilled workers to function properly and is associated with high acquisition and maintenance costs**[11].**

3. X-Ray Diffraction:

A common technique for analyzing atomic spacings and crystalline structures is X-ray diffraction. This technique provides information on phases, topologies, desired textures, and other structural characteristics like average grain size, crystallinity, strain, and lattice parameters. The constructive interference of a coherent X-ray beam reflected at particular angles from each pair of crystal planes within a material produces the patterns seen in X-ray diffraction. The arrangement of atoms within the crystal lattice determines the intensity of the peaks in the diffraction pattern.

An X-ray tube, a sample stage, and an X-ray detecting sensor are the three main parts of an X-ray diffractometer. Initially, a cathode ray tube emits electrons through a heated filament, which are then accelerated by voltage towards the sample target. Diffractograms are the term used to describe the output of the XRD instrument. The y-axis shows the intensity, and the x-axis shows the scanning angle. The diffractogram's peaks' width and form reveal details about antiphase boundaries, stacked faults, and crystallite size. X-ray diffraction is widely used in thin-film observations, texture analysis, and stress-strain observations in addition to crystalline structure and phase analysis[12].

4. Scanning electron microscopy:

Visualising sample surfaces is made possible by the scanning electron microscope (SEM), which picks up secondary electrons released when an electron beam interacts with the sample. Surface sensitivity and shallow beam penetration are the results of SEM's use of lower beam energies than TEM. As a result, SEM can be used to analyse the morphology of "thick" samples (>100 nm), something that TEM cannot do. In comparison to TEM, SEM is more user-friendly, quicker, and less expensive to maintain, but it also offers moderate resolution (>2–3 nm) and a lower chance of sample damage. High-resolution imaging with SEM usually requires conductive substrates, and nonconductive samples might require a thin metallic film coating. When analysing SEM images, it's critical to take sample preparation into account as it affects the size and surface structure of non-conductive nanoparticles. Furthermore, surface structure information is provided by SEM, and sample structure throughout its volume is revealed by TEM[11].

5. Fourier Transform Infrared (FT-IR) Spectroscopy:

The identification of chemical residues on the surface of silver nanoparticles (Ag NPs) as well as the roles that chemicals and metabolites play in the reduction and capping of Ag NPs are made possible by Fourier transform infrared spectroscopy (FTIR). This method is based on the interaction of molecular bonding with infrared electromagnetic radiation, which produces observable stretching and bending vibrations that are usually located in the 4000-400 cm^-1 region. Fastness, economy, non-destructiveness (especially with the attenuated total reflectance accessory), and excellent repeatability are the reasons why FTIR is highly regarded. It mostly offers qualitative insights, though, and has a limited sensitivity to nanoscale analysis. The role of functional groups such as amide (-CO-NH2), carbonyl (-CO), and hydroxyl (-OH) in mediating the reduction, capping, and stabilization of Ag NPs is highlighted by FTIR spectral analysis[13].

APPLICATIONS:

AgNPs find utility across various domains such as thin films[14], surface coatings[15], batteries[16], energy harvesting[17], and conductors[18]. However, it is their application in clinical settings that has garnered significant attention, owing to the escalating global threat of hazardous diseases and the challenge of multidrug resistance in conventional drug delivery systems. AgNPs are widely recognized for their ability to combat a broad spectrum of infections, despite being economically limited in feasibility.

When AgNPs interact with host/pathogenic cell proteins and enzymes, they cause cell death and demonstrate strong antimicrobial properties. Ag+ ions are released during their antibacterial actions, and this produces reactive oxygen species that interfere with vital protein functions and bacterial growth signalling pathways. Silver ions also covalently bind to bacterial cell surfaces, disrupting cell membranes and inhibiting essential cellular processes. Additionally, Ag+ particles interact with tyrosinaseenzymes and proteins in bacterial membranes and cytoplasm[19], crucial for bacterial respiration and substance transport, further contributing to their antimicrobial efficacy[20]. Moreover, silver particles are recognized for their effectiveness in preventing wound infections[21].

Functionalized AgNPs, along with those combined with antimicrobials, have demonstrated effectiveness. Recent advancements include the incorporation of AgNPs into polymer matrices[22], enhancing their reactivity. Numerous studies have explored their diverse biomedical properties, including insecticidal, antilarval, antibiofilm, and anticancer effects[23].

Research design would be aided and additional research into the effectiveness of AgNPs in clinical applications would be encouraged with a comprehensive review that includes tables and schematic representations to help with understanding of the many facets of AgNPs.

1. ***Drug Delivery***

Nanoparticles containing one or more therapeutic drugs that can bind, scatter, or absorb into polymer matrices are a common component of nanotechnology-based drug delivery systems. The creation of nanodrugs for diagnosis, treatment, and imaging has significantly increased in recent years. These systems are principally focused on improving the oral administration of pharmaceuticals, extending the half-life of injectable drugs, and improving the bioavailability of targeted tissue delivery. Most of the time, nano-drugs are used at lower dosages, which improves their pharmacological effects and lowers risks to health and adverse reactions[24].

2. ***Potential Applications of Nanoparticles:***

- Antimicrobial assay

Silver nanoparticles, or AgNPs, are naturally occurring antimicrobial agents that have the ability to inhibit a variety of microorganisms, including yeasts, Escherichia coli, and Staphylococcus aureus. In the pharmaceutical sector, they provide a number of benefits for the treatment of viral and bacterial illnesses[25]. Their efficiency against clinical bacteria, such as extended-spectrum beta-lactamase (ESBL) and multidrug-resistant (MDR) bacteria, is especially remarkable[22].

AgNPs demonstrate higher antibacterial activities compared to silver itself, primarily due to their wide surface areas and greater surface molecule divisions[26]. Because of these properties, AgNPs are able to enter bacterial cells and cause cell death. AgNPs damage DNA and interfere with cellular processes when they enter bacterial cells. Additionally, when they attach to proteins that contain sulphur, the bacterial cell wall is broken down and protein synthesis is inhibited[27]. AgNPs further suppress harmful microbes by encouraging the generation of reactive oxygen species (ROS), such as hydrogen peroxide[28].

AgNPs synthesised using the fungus Fusarium Oxysporum have shown antibacterial activity and could be incorporated into textiles to reduce the risk of Staphylococcus aureus infections in hospitals[29].

Size, shape, and surface charge are some of the variables that affect AgNPs' antibacterial activities. As an illustration, the most potent antibacterial properties are found in triangular silver nanoplates with large surface area-to-volume ratios and crystal structures[30]. AgNPs with a positive charge have a greater inhibitory effect on gram-negative bacteria even though they are more resistant than gram-positive bacteria[31].

Table 1. Silver nanoparticles and their antimicrobial activities[32].

Organisms used for AgNPs synthesis	**Pathogenic Bacteria**
Fungus *Alternarnia* sp.	*Bacillus sutilis, Staphylococcus aureus, Escherichia coli* and *Serratiamarcescens*
Actinobacteria *Streptaciphilusdurhamensis*	*Pseudomonas aeruginosa, Staphylococcus aureu sand Proteus mirabilis*
Lysinibacillusvarians	*Candida albicans* and *Candida glabrata*
Root extract of *Helicteresisora*	*Bacillus subtilis* and *Micrococcus luteus*
Bacterium *Orchrobactrumanhtropi*	*Salmonella typhi, Salmonella paratyphi, Vibrio cholerae and Staphylococcus aureus*
Fruit Dimocarpus Longan Lour. Peel	*Escherichia coli* and *Staphylococcus aureus*

Information about the antibacterial properties of AgNPs made from different organisms against distinct pathogenic bacteria is probably shown in Table 1 of the text.Overall, AgNPs offer promising potential in combating microbial infections, and their properties can be optimized for specific applications through careful design and synthesis.

- Anti-inflammatory

The immune system uses inflammation as a reaction to infections and cell damage in the body. Its goals include getting rid of dangerous substances and helping the body's tissues reorganize and restore cell function[33]. Different inflammatory disorders can arise as a result of this intricate process of dysregulation[34]. Keratinocytes produce immune-regulatory substances like cytokines and interleukins during an inflammatory response[35]. The primary immune organs release cytokines like IL-1 and IL-2, which are potential anti-inflammatory agents, to start the healing process, while the endocrine system secretes some inflammatory mediators like enzymes and antibodies[36].

Positive impacts on tissue regeneration and wound healing have been shown for biosynthesized gold and platinum nanoparticles[37]. Table 2 enumerates certain silver nanoparticles (AgNPs) that exhibit anti-inflammatory properties. Plant-derived AgNPs have been observed to induce cytokine production, potentially because the plants' alkaloids or flavonoids function as coating agents and add further pharmacological characteristics[34].

Increased nanosilver dosages have been shown to stimulate Th1 cell production and the release of inflammatory cytokines, such as IL-2 and INF-γ, which are essential for cellular immunity[38]. In human peripheral blood mononuclear cells, AgNPs coated with alkaloids from unripe fruits of Piper nigrum exhibit increased anti-inflammatory activity[34]. Additionally, AgNPs synthesized from various plants, such as Pteris tripartite[39], Acalyphaindica, Garciniamangostana[38], Centratherumpunctatum Cass, Rosa damascene[40], and Abutilon indicum[37], have exhibited anti-inflammatory activities.

Table 2. Role of bio-synthesized AgNPs in anti-inflammation[32].

Organisms used for AgNPs Synthesis	**Constituents as Stabilizing Agents**	**Production of Anti inflammatory Agents**
Terminalia sp. *(T. bentazoe, T. billerica, T. mellueri and Terminaliacatapa)* leaves	Poysaccharides, protein, polyphenolic and flavanoid compounds	Reactive oxygen species (ROS)
Leaf extract of *PteristripartitaSw*	Phenolics, flavonoids, terpenoids, tannins, proteins and glycosides	Histamine, serotonin and Prostaglandins

Plant *Leucasaspera* (willd.), *Abutilon indicum*	Terpenoids, alkaloids, flavonoids,phenol, tannins, phytosterols, carbohydrates, aromatics, aldehydes, alkenes, aromatics, alkyl halides, aliphatic amines, amines	Indomethacin

- Anticancer Activity of Silver Nanoparticles

With its ability to create new, more invasive, and targeted therapeutic approaches, nanomedicine presents a great deal of promise for the treatment of cancer[41]. One particularly intriguing area of research is the use of metallic nanoparticles (NPs) for cancer diagnostics and treatment[42].

Metallic NPs offer several advantages that make them attractive for cancer therapy. First and foremost, their special qualities enable high penetration and target specificity, which makes them useful for both treatments and diagnostics[43]. Furthermore, peptides, monoclonal antibodies, DNA/RNA, and tumour markers can all be functionalized onto metallic NPs. As a result, highly targeted approaches that can bind to cancer cell surface proteins or receptors with selectivity can be developed.

Through the application of nanobiotechnology, scientists can create therapeutic agents in nanoparticle form that target cancer cells directly, minimizing harm to healthy tissue and minimizing side effects. Furthermore, the ability to incorporate multiple functionalities into metallic NPs enables multimodal imaging and therapy, providing clinicians with valuable tools for both diagnosis and treatment[44].

All things considered, using metallic nanoparticles in cancer research is a promising way to create new, more potent anticancer treatments. The potential for substantial improvements in cancer patient outcomes while reducing the side effects of conventional treatments is present for further research and development in this area[45].

- Insecticidal Activity of AgNPs.

Diseases and insects are major threats to commercial and food-producing crops in agriculture. Pests are defined as insects that feed on plants and can harm developing leaves, fruits, and vegetables. Chemical pesticides are widely used to control pests, but this practice can have detrimental effects on ecosystems that can affect human health[46], biodiversity loss, disrupt nitrogen fixation[47], and destroy habitats[48].

Researchers have suggested using formulations of nanopesticides to manage crop pests and diseases to address these issues. Nano-pesticides offer several advantages over traditional chemical pesticides, including increased efficacy and reduced environmental impact. In particular, biosynthesized silver and lead nanoparticles are gaining attention due to their availability[49], safety (non-carcinogenic), and diverse biological activities[50].

For example, silver nanoparticles (AgNPs) synthesized using extracts from plants like Euphorbia prostrata have shown insecticidal activity against pests such as Sitophilusoryzae, which commonly infests rice, wheat, and maize grains. These AgNPs offer a potential alternative to conventional chemical insecticides for controlling pest populations[51].

Additionally, research on AgNPs and sulfur nanoparticles (S NPs) derived from diverse sources has shown their insecticidal activities against the fruit fly Drosophila melanogaster at different life stages (larval, pupal, and adult). While both types of nanoparticles exhibited insecticidal effects, AgNPs derived from olive and mulberry showed particularly high mortality rates and significantly reduced larval longevity.

Overall, the development and application of nano-pesticides, particularly those synthesized from natural sources, hold promise for sustainable pest management in agriculture. Further research into the efficacy, safety, and environmental impacts of these nano-pesticides is essential to their widespread adoption and integration into agricultural practices.

- Antibiofilm Activity of AgNPs.

Biofilms are compact collections of microbial cells that self-assemble into polymeric structures on a variety of biotic and abiotic surfaces[52]. Since a large amount of Earth's biomass exists in biofilm states, providing protection and resilience to external pressures, this mode of growth is thought to be highly advantageous for microorganisms. Biofilms produced by pathogenic bacteria, however, present serious problems in clinical settings and can result in several infectious diseases.

The application of nanoparticles (NPs) in the fight against biofilms has been well-researched and recorded. By using electrostatic forces to interact with the bacterial layers, these NPs damage the integrity of the biofilms. NPs have a high surface-to-volume ratio that allows them to deeply penetrate established biofilms, which increases their effectiveness as antibiofilm agents.

Numerous studies have examined the biologically synthesized NPs' antibiofilm properties, concentrating on pathogenic bacteria that are clinically significant, like *Klebsiella pneumoniae*. For example, biofilm formation by *Escherichia coli* and *Pseudomonas aeruginosa* was effectively reduced by up to 70% when silver (Ag) nanoparticles synthesized using the fungus *Aspergillus flavus* were added at a concentration of 0.2 μg/mL[53].

Similarly, over 50% of the biofilm formation by *Pseudomonas aeruginosa* and *Staphylococcus aureus* was inhibited by AgNPs synthesized with *Emericella nidulans* at 4 μg/mL. AgNPs derived from *Zingiber officinal*e plant were able to completely inhibit biofilm formation at remarkably low concentrations (0.0596 μg/mL for *Klebsiella pneumoniae* and 0.0683 μg/mL for *Staphylococcus aureus*)..

Another study demonstrated that gold (Au) NPs synthesized with a bacteriophage at a concentration of 0.2 mM inhibited 80% of biofilm formation by *Pseudomonas aeruginosa*.

In summary, the utilization of biosynthesized NPs, particularly silver and gold nanoparticles, shows promising antibiofilm activities against various pathogenic bacteria, offering potential solutions for combating biofilm-related infections.

CONCLUSIONS:

Nanoparticles at the nanoscale exhibit significant positive impacts across diverse fields, including their utilisation in various applications within the food industry. Through modifications at the nanolevel, their properties and functions can be tailored to benefit food-related processes.The food packaging and processing industry has made extensive use of nanotechnology, which has led to improvements in antimicrobial paints, textiles, air purification, wastewater treatment, dentistry, plastic materials, ceramics, food preservation, and viruses and bacteria control. In agriculture, nanoparticles are employed for controlling pests, insects, larvae, and pupae through the development of nanoparticle pesticides (NPPs), nanobiopesticides (NBPs), nanofilters, nanofertilizers, and other innovations.

ACKNOWLEDGMENTS:

The authors are thankful to the Management, Principal of Sarojini Naidu Vanita Pharmacy MahaVidyalaya, Osmania University, Hyderabad, India for providing research facilities.

REFERENCES:

1. Scott E McNeil, Nanotechnology for the biologist Journal of Leukocyte Biology, Volume 78, Issue 3, Sep 2005, Pages 585–594.
2. NadeemJoudeh and Dirk Linke, Nanoparticle classifcation, physicochemical properties, characterization, and applications:a comprehensive review for biologists, Journal of Nanobiotechnology (2022) 20:262, https://doi.org/10.1186/s12951-022-01477-8
3. Xi-Feng Zhang, Silver Nanoparticles: Synthesis, Characterization, Properties, Applications, and Therapeutic Approaches, Int J Mol Sci. 2016 Sep; 17(9): 1534, doi: 10.3390/ijms17091534
4. Ebtihal Ahmed Mergani, Biosynthesis of Silver Nanoparticles and its Antibacterial activity using Black Pepper(Pipernigrum), International Journal of Recent Scientific Research Vol. 7, Issue 2, pp. 8766-8771, February, 2016
5. Anu Mary Ealias, A review on the classification, characterisation, synthesis of nanoparticles and their application , 017 *IOP Conf. Ser.: Mater. Sci. Eng.* 263 032019 DOI: 10.1088/1757-899X/263/3/032019
6. Ibrahim Khan, Nanoparticles: Properties, applications and toxicities, Arabian Journal of Chemistry Volume 12, Issue 7, November 2019, Pages 908-931
7. Bipin D. Lade, Phytonanofabrication: Methodology and Factors Affecting Biosynthesis of Nanoparticles, Smart Nanosystems for Biomedicine, Optoelectronics and Catalysis, Published: 21 January 2020, DOI: 10.5772/intechopen.90918
8. Iravani S, Korbekandi H, Mirmohammadi SV, Zolfaghari B. Synthesis of silver nanoparticles: chemical, physical and biological methods. Res Pharm Sci. 2014 Nov-Dec;9(6):385-406. PMID: 26339255; PMCID: PMC4326978.
9. IrfanIjaz, Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles, Green Chemistry Letters and Reviews ,Volume 13, 2020 - Issue 3, Pages 223-245
10. Workneh M. Shume, H. C. Ananda Murthy, EnyewAmareZereffa, "A Review on Synthesis and Characterization of Ag2O Nanoparticles for Photocatalytic Applications", *Journal of Chemistry*, vol. 2020, Article ID 5039479, 15 pages, 2020. https://doi.org/10.1155/2020/5039479
11. Mario M. Modena, Nanoparticle Characterization: What to Measure?, Adv. Mater. 2019, 1901556, https://doi.org/10.1002/adma.201901556
12. PraveenkumaraJagadeesh, Advanced characterization techniques for nanostructured materials in biomedical applications, Advanced Industrial and Engineering Polymer Research, Volume 7, Issue 1, January 2024, Pages 122-143
13. SonikaDawadi,, "Current Research on Silver Nanoparticles: Synthesis, Characterization, and Applications", *Journal of Nanomaterials*, vol. 2021, Article ID 6687290, 23 pages, 2021. https://doi.org/10.1155/2021/6687290
14. Yeo, C.I.; Choi, J.H.; Kim, J.B.; Lee, J.C.; Lee, Y.T. Spin-coated Ag nanoparticles for enhancing light absorption of thin film a-Si:H solar cells. Opt. Mater. Express 2014, 4, 346-351, http://dx.doi.org/10.1364/OME.4.000346.
15. Jo, Y.K.; Seo, J.H.; Choi, B.-H.; Kim, B.J.; Shin, H.H.; Hwang, B.H.; Cha, H.J. Surface-Independent Antibacterial Coating Using Silver Nanoparticle-Generating Engineered Mussel Glue. ACS Applied Materials & Interfaces 2014, 6, 20242-20253, http://dx.doi.org/10.1021/am505784k.
16. Bindumadhavan, K.; Chang, P.-Y.; Doong, R.-a. Silver nanoparticles embedded boron-doped reduced graphene oxide as anode material for high performance lithium ion battery. Electrochim. Acta 2017, 243, 282-290, https://doi.org/10.1016/j.electacta.2017.05.063.

17. FeiGuo, C.; Sun, T.; Cao, F.; Liu, Q.; Ren, Z. Metallic nanostructures for light trapping in energy-harvesting devices. Light: Science & Applications 2014, 3, e161-e161, https://doi.org/10.1038/lsa.2014.42.

18. Gerardo, C.D.; Cretu, E.; Rohling, R. Fabrication of Circuits on Flexible Substrates Using Conductive SU-8 for Sensing Applications. Sensors 2017, 17, http://dx.doi.org/10.3390/s17061420.

19. Shrivastava, S.; Bera, T.; Roy, A.; Singh, G.; Ramachandrarao, P.; Dash, D. Characterization of enhanced antibacterial effects of novel silver nanoparticles. Nanotechnology 2007, 18, 225103, http://dx.doi.org/10.1088/0957-4484/18/22/225103.

20. Shankar, P.D.; Shobana, S.; Karuppusamy, I.; Pugazhendhi, A.; Ramkumar, V.S.; Arvindnarayan, S.; Kumar, G. A review on the biosynthesis of metallic nanoparticles (gold and silver) using bio-components of microalgae: Formation mechanism and applications. Enzyme Microb. Technol. 2016, 95, 28-44, http://dx.doi.org/10.1016/j.enzmictec.2016.10.015.

21. Wright, J.B.; Lam, K.; Hansen, D.; Burrell, R.E. Efficacy of topical silver against fungal burn wound pathogens. Am. J. Infect. Control 1999, 27, 344-350, http://dx.doi.org/10.1016/S0196-6553(99)70055-6.

22. MubarakAli, D.; Arunkumar, J.; Pooja, P.; Subramanian, G.; Thajuddin, N.; Alharbi, N.S. Synthesis and characterization of biocompatibility of tenorite nanoparticles and potential property against biofilm formation. Saudi Pharmaceutical Journal 2015, 23, 421-428, https://doi.org/10.1016/j.jsps.2014.11.007.

23. Pugazhendhi, A.; Prabakar, D.; Jacob, J.M.; Karuppusamy, I.; Saratale, R.G. Synthesis and characterization of silver nanoparticles using Gelidiumamansii and its antimicrobial property against various pathogenic bacteria. Microb. Pathog. 2018, 114, 41-45, http://dx.doi.org/10.1016/j.micpath.2017.11.013.

24. AbidHaleem, Applications of nanotechnology in medical field: a brief review, Global Health Journal, Volume 7, Issue 2, June 2023, Pages 70-77

25. Song, J.Y.; Kim, B.S. Biological synthesis of bimetallic Au/Ag nanoparticles using Persimmon (Diopyros kaki) leaf extract. Korean J. Chem. Eng. 2008, 25, 808-811, http://dx.doi.org/10.1007/s11814-008-0133-z.

26. Durán, N.; Marcato, P.D.; Conti, R.D.; Alves, O.L.; Costa, F.; Brocchi, M. Potential use of silver nanoparticles on pathogenic bacteria, their toxicity and possible mechanisms of action. J. Braz. Chem. Soc. 2010, 21, 949-959, http://dx.doi.org/10.1590/S0103-50532010000600002.

27. Sondi, I.; Salopek-Sondi, B. Silver nanoparticles as antimicrobial agent: a case study on E. coli as a model for Gram-negative bacteria. J. Colloid Interface Sci. 2004, 275, 177-182, http://dx.doi.org/10.1016/j.jcis.2004.02.012.

28. Mohammed, A.E. Green synthesis, antimicrobial and cytotoxic effects of silver nanoparticles mediated by Eucalyptus camaldulensis leaf extract. Asian Pacific Journal of Tropical Biomedicine 2015, 5, 382-386, http://dx.doi.org/10.1016/S2221-1691(15)30373-7.

29. Gade, A.K.; Bonde, P.; Ingle, A.P.; Marcato, P.D.; Durán, N.; Rai, M.K. Exploitation of Aspergillusniger for Synthesis of Silver Nanoparticles. Journal of Biobased Materials and Bioenergy 2008, 2, 243-247, http://dx.doi.org/10.1166/jbmb.2008.401.

30. Pal S, Tak YK, Song JM. Does the antibacterial activity of silver nanoparticles depend on the shape of the nanoparticle? A study of the Gram-negative bacterium Escherichia coli. Appl. Environ. Microbiol. 2007, 73, 1712, http://dx.doi.org/10.1128/AEM.02218-06.

31. Panda, B.S.; Ahemad, M.A.; Mishra, L.N. Green Synthesized Nanoparticles & An approach towards Antibacterial & Antimicrobial activities: A Review, International Journal of ChemTech Research 2021, 14, 16-41, https://doi.org/10.20902/IJCTR.2021.140103.

32. Bhabani Shankar Panda, A Review on Synthesis of Silver Nanoparticles and their Biomedical Applications, Review, Letters in Applied NanoBioScience, Open-Access Journal (ISSN: 2284-6808), Volume 11, Issue 1, 2022, 3218 – 3231, https://doi.org/10.33263/LIANBS111.32183231

33. Chuchawankul, S.; Khorana, N.; Poovorawan, Y. Piperine inhibits cytokine production by human peripheral blood mononuclear cells. Genet. Mol. Res. 2012, 11, 617-627, http://dx.doi.org/10.4238/2012.March.14.5.

34. Mani, A.K.M.; Seethalakshmi, S.; Gopal, V. Evaluation of in-vitro anti-inflammatory activity of silver nanoparticles synthesised using piper nigrum extract. Journal of Nanomedicine& Nanotechnology 2015, 6, 1.

35. Baskaran, X.; Vigila, A.V.G.; Parimelazhagan, T.; Muralidhara-Rao, D.; Zhang, S. Biosynthesis, characterization, and evaluation of bioactivities of leaf extract-mediated biocompatible silver nanoparticles from an early tracheophyte, Pteristripartita Sw. International journal of nanomedicine 2016, 11, 5789, http://dx.doi.org/10.2147/IJN.S108208.

36. Kaliamurthi, S.; Selvaraj, G.; V, D.; Ramanathan. HeliotropiumCurassavicum mediated Silver Nanoparticles for Environmental Application. Research Journal of Chemistry and Environment 2013, 17, 27-33.

37. Rajakannu S, Shankar S, Perumal S, Subramanian S, Dhakshinamoorthy, G. Biosynthesis of Silver Nanoparticles using Garciniamangostana Fruit Extract and their Antibacterial , Antioxidant Activity. Int J CurrMicrobiolApplSci 2015, 4, 944-952.

38. Ahmad, N.; Bhatnagar, S.; Ali, S.S.; Dutta, R. Phytofabrication of bioinduced silver nanoparticles for biomedical applications. Int J Nanomedicine 2015, 10, 7019-7030, https://doi.org/10.2147/ijn.S94479.

39. Kumaran, N.S. biosynthesis of silver nanoparticles using Abutilon indicum (Link): An investigation of antiinflammatory and antioxidant potential against carrageen induced paw edema in rats. Asian Journal of Pharmaceutics (AJP): Free full text articles from Asian J Pharm 2017, 11

40. Araj S-EA, Salem NM, Ghabeish IH, Awwad AM. Toxicity of nanoparticles against Drosophila melanogaster (Diptera: Drosophilidae). Journal of Nanomaterials 2015, 2015, 758132, http://dx.doi.org/10.1155/2015/758132. 96.

41. Thao Truong-Dinh, T.; Phuong Ha-Lien, T.; Yichao, W.; Puwang, L.; Lingxue, K. Nanoparticulate Drug Delivery to Colorectal Cancer: Formulation Strategies and Surface Engineering. Curr. Pharm. Des. 2016, 22, 2904-2912, http://dx.doi.org/10.2174/1381612822666160217140932. 104.

42. Khalil, A.T.; Ovais, M.; Ullah, I.; Ali, M.; Shinwari, Z.K.; Hassan, D.; Maaza, M. Sageretiathea (Osbeck.) modulated biosynthesis of NiO nanoparticles and their in vitro pharmacognostic, antioxidant and cytotoxic potential. Artificial cells, nanomedicine, and biotechnology 2018, 46, 838-852, https://doi.org/10.1080/21691401.2017.1345928. 105.

43. Saravanan, M.; Vemu, A.K.; Barik, S.K. Rapid biosynthesis of silver nanoparticles from Bacillus megaterium (NCIM 2326) and their antibacterial activity on multi drug resistant clinical pathogens. Colloids Surf. B. Biointerfaces 2011, 88, 325-331, http://dx.doi.org/10.1016/j.colsurfb.2011.07.009.

44. Erathodiyil, N.; Ying, J.Y. Functionalization of Inorganic Nanoparticles for Bioimaging Applications. Acc. Chem. Res. 2011, 44, 925-935, http://dx.doi.org/10.1021/ar2000327.

45. Justin Packia Jacob, S.; Finub, J.S.; Narayanan, A. Synthesis of silver nanoparticles using Piper longum leaf extracts and its cytotoxic activity against Hep-2 cell line. Colloids Surf. B. Biointerfaces 2012, 91, 212-214, http://dx.doi.org/10.1016/j.colsurfb.2011.11.001.

46. Palmer, W.E.; Bromley, P.T.; Brandenburg, R.L. Wildlife & pesticides-peanuts. North Carolina Cooperative Extension Service; 2007, 10-11.

47. Palaniappan, P.; Sathishkumar, G.; Sankar, R. Fabrication of nanosilver particles using Cymodoceaserrulata and its cytotoxicity effect against human lung cancer A549 cells line. SpectrochimicaActa Part A: Molecular and Biomolecular Spectroscopy 2015, 138, 885-890, http://dx.doi.org/10.1016/j.saa.2014.10.072.

48. Yasur, J.; Usha Rani, P. Lepidopteran insect susceptibility to silver nanoparticles and measurement of changes in their growth, development and physiology. Chemosphere 2015, 124, 92-102, http://dx.doi.org/10.1016/j.chemosphere.2014.11.029.

49. Awwad, A.M.; Salem, N.M. Green synthesis of silver nanoparticles byMulberryLeavesExtract. Nanoscience and Nanotechnology 2012, 2, 125-128, http://dx.doi.org/10.5923/j.nn.20120204.06.

50. Miquel, S.; Lagrafeuille, R.; Souweine, B.; Forestier, C. Anti-biofilm Activity as a Health Issue. Front. Microbiol. 2016, 7, 592, http://dx.doi.org/10.3389/fmicb.2016.00592. 93.

51. Baelo, A.; Levato, R.; Julián, E.; Crespo, A.; Astola, J.; Gavaldà, J.; Engel, E.; Mateos-Timoneda, M.A.; Torrents, E. Disassembling bacterial extracellular matrix with DNase-coated nanoparticles to enhance antibiotic delivery in biofilm infections. J. Controlled Release 2015, 209, 150-158, http://dx.doi.org/10.1016/j.jconrel.2015.04.028. 95.

52. Nithya, B.; Jayachitra, A. Improved antibacterial and antibiofilm activity of plant mediated gold nanoparticles using Garcinia cambogia. Int. J. Pure App. Biosci 2016, 4, 201-210, http://dx.doi.org/10.18782/2320- 7051.2238.

53. Kirtane, A.R.; Kalscheuer, S.M.; Panyam, J. Exploiting nanotechnology to overcome tumor drug resistance: Challenges and opportunities. Adv. Drug Del. Rev. 2013, 65, 1731-1747, http://dx.doi.org/10.1016/j.addr.2013.09.001.