Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
 ISSN 1118 – 1931

GREEN SYNTHESIZED SILVER NANOPARTICLES AND THEIR BIOMEDICAL APPLICATIONS: A REVIEW

[1]Akinsipo (Oyelaja), O. B., [2]Osinubi, A. D., [3]Badeji, A. A., [4]Ogunade, T. J., [5]Idowu, A. D. [6]Afolayan, O. J. [7]Ajiwe, I. A. , and [8]Ameen, A. O

[1,2,3,4,5,6,7,8] *Department of Chemical Sciences, College of Science and Information Technology, Tai Solarin University of Education.*

Corresponding author:solape2010@gmail.com; akinsipoob@tasued.edu.ng ; +2348166617462

Received: 18-06-2023
Accepted: 14-02-2024

https://dx.doi.org/10.4314/sa.v23i3.2

Journal Homepage: http://www.scientia-african.uniportjournal.info
Publisher: *Faculty of Science, University of Port Harcourt.*

ABSTRACT

Over the last two decades, scientists have become increasingly interested in metallic nanoparticles due to their unique properties, especially in the biomedical field. Green synthesis of metal nanoparticles is a rapidly growing field in nanotechnology due to its viability, reduced toxicity, eco-friendly nature, and ease of preparation. Plants have long been a centre of attraction in the field of medicine because they are a unique source of a variety of bioactive compounds. Silver has been known for its medicinal properties, especially its antibacterial therapeutic effect. Among other metal nanoparticles, silver nanoparticles have taken a special place since it has made a big impact on medical applications. This review aims to provide a comprehensive understanding of the biomedical qualities of medicinal plants, as well as an overview of their impact on the synthesis of green silver nanoparticles. Various biomedical applications of plant-mediated silver nanoparticles will also be highlighted.

Keywords: Silver nanoparticles; Green synthesis; Biomedical applications; Nanotechnology

INTRODUCTION

Nanotechnology has earned substantial attention in the present century due to its distinctive properties. This makes it an efficient candidate in the multidisciplinary field and in numerous applications (Muhammed, 2022). Nanotechnology comprises the synthesis of nanoparticles (NPs) with various sizes, morphology, and dispersity to be used for their advantage in different ways. It also involves the production of nanostructures with sizes ranging from 1 to 100 nm (Kumar *et al.,* 2018). A nanoparticle (NPs) is a small particle having enhanced properties because of the atomic interaction on its surface, resulting in less coordination than that displayed in bulk materials (Njud, 2022). NPs can be made of metal or non-metal depending on their basic form. Metallic NPs consist of silver, gold, copper, magnetic (cobalt nickel) and semiconducting materials. In contrast, non-metallic nanoparticles are primarily composed of carbon-based materials.

Silver (Ag) is a non-toxic inorganic agent capable of eliminating approximately 650 different types of diseases using microorganisms, therefore, it forms the most essential nanoparticles due to its unique physicochemical properties (Xu*et al.,* 2020).

Silver has been described as dynamic because of its ability to exert excellent potential for biological uses, including anti-fungal, anti-bacterial, anti-viral, wound healing and anti-inflammatory properties at low concentrations (HabeebRahuman *et al*., 2022). Silver nanoparticles (AgNPs) among other nanoparticles have received extensive attention because of their unique properties (Mustapha *et al*., 2022). Synthesis of AgNps can be achieved either through a top-down or bottom-up approach. The top-down approach involves breaking down a built material into nano-sizes using sophisticated physical techniques such as laser ablation and sputtering. Meanwhile, the bottom-up approach refers to building nanoparticles using smaller entities such as chemical and biological materials. This chemical method requires the use of highly toxic and expensive chemicals, which are difficult to use at a large scale leading to the synthesis of highly toxic nanoparticles (Mohd*et al*., 2012). However, the biological method which is also referred to as green synthesis was chosen over chemical and physical methods because they are clean, safe, easy to prepare, non-toxic, environmentally- friendly and cost-effective (Christophe and Bilal, 2021). As a result, several biological systems such as bacteria, fungi, yeast, and plant are presently broadly empowered in green synthesis for the creation of AgNPs (Mattew *et al*., 2021).

AgNPs synthesized with plants are by far the most important biological entity as their comprehensive abundance and lack of pathogenicity offer an advantage over other biological sources. In addition, plant-mediated synthesis is comparably mild with their phytochemical and bioactive contents acting as reducing, capping, and stabilizing agents. Numerous studies have reported the victorious synthesis of AgNPs using different plant species. At their nanoscale size, the AgNPs exhibit significantly different characteristics, as well as improved bioactivity, compared to their bulk counterpart. Green nanoparticles synthesised with plants appear to provide controlled particle size and shape, which is critical for a wide range of medical applications. The benefit of following synthesis by biological means using plant parts like stems, roots, leaves, bark, flower, peels e.t.c includes non-toxicity, easy reproducibility, and cost-effectiveness. On the other side, the use of plant extract as a reducing agent has also become promising because they contain biomolecules such as carbohydrates, protein, and co-enzymes that possess the capability of reducing metal ions to metal nanoparticles (Alayande*et al.,* 2021; Salem and Fouda, 2021).

This review is aimed at giving a general overview of the role of plants towards successful synthesis of green AgNPs and to discuss the effective medical potential of green synthesized AgNPs.

Nanoparticles and their classification

European Union (EU) in 2011 defined nanoparticles "as natural or manufactured material which contain particles in an unbound state or as an agglomerate or an aggregate and where 50 percent or more of the particles in the number size distribution, one or more external dimension is in size range 1 to 100 nm". Nano objects requires only one of its characteristics dimension in the size range of 1 to 100 nm to be classified as nanoparticle, even if their other dimensions are outside that range. NPs have an impressively long history. They either exist freely in nature or are artificial. Examples of NPs which exist naturally include organic compounds (such as viruses, bacteria, proteins and polysaccharides) and inorganic compounds (such as natural dust, aluminosilicate and iron oxyhydroxides) which are produced by volcanic eruptions microbial processes, weathering and wildfires (Griffin *et al.,* 2018).

The classification of NPs depends basically on the number of dimensions that lie within the nanometer range (Mishra *et al.,* 2012). Nanoparticles are classified into two main types: organic and inorganic nanoparticles. Organic nanoparticles comprise lipid NPs (micelle, liposome and nanocapsule),

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

dendrimer, hybrid, nanosphere, compact polymeric and nanocapsule and the inorganic NPs; Fullerene, quantum dot, some metallic NPs (silica metal, palladium, silver, lead, Gold, platinum, Ruthenium and Copper (Das *et al*., 2019).

Organic nanoparticles

Micelles are lipid molecule that arranges themselves spherically in an aqueous solution while micelles form, they respond to the amphipathic nature of fat acids (polymers of lipid), which means that they have both the hydrophobic and the hydrophilic end. The main reason for this spherical formation is because of the hydrophobic interaction, the molecules experience, on exposure to aqueous surrounding separated from water, this lead to the water forming an organised enclosure around the hydrophobic tail (Das *et al.*, 2019). Dendrimers are nano-sized radially symmetric molecules with well-defined, similar and monodispersed structures (Abbasi*et al.,* 2014). Dendrimers are tremendously branched, spherical and multivalent molecules with artificial elastic and several probable usages extruding from catalysis to electronics and drug discharge (Wang *et al.,* 2022). The size of these NPs is effortlessly managed by the number of production. Liposomes are spherical vesicles containing phospholipid bilayers. They are formed from cholesterol and natural phosphides because of their size, hydrophobic and hydrophilic nature. They are encouraging systems for drug delivery with their properties varying significantly with the composition of phosphide's surface charge, size and the mode of preparation (Akbarzardeh*et al*., 2013). The main advantages of liposomes are that they are recyclable, compatible, non-toxic and non-immunogenic (Das *et al.,* 2019). Nanosphere are particles with a size range between 10 to 200 nm in diameter. They are amorphous and it has been revealed that the hydrophobic areas of these particles are extremely vulnerable to the action of phagocytes (Walia*et al.,* 2018). A nanocapsule is made up of a shell and a space in which a preferred substance may be placed. Nanocapsules are made from phospholipid molecules, which are hydrophobic on one end and hydrophilic on the other end and when such molecules are placed in an aqueous environment, they can form capsules spontaneously where the hydrophobic portions are enclosed, protecting them from water contact (Naymih*et al*., 2019). Fullerenes comprise symmetrical and stable carbon molecules and the most popular fullerene is the inflexible icosahedrons (a polyhedron with 20 faces) with 60 carbon atoms. They are said to be three-dimensional analogues of benzene. Fullerenes are highly strong molecules able to resist high pressures (Amini, 2019). Quantum dots are semiconductors. They are tiny devices that contain droplets of small electrons. They are also referred to as nanometer-sized crystals (Vorobyova*et al.,* 2019).

Inorganic nanoparticles

Inorganic molecules for example Au (Gold) Ag (silver) PT (platinum) and silica may be employed to generate nanoparticles. Inorganic NPs as shown in Figure 1 below are synthesized through numerous methods, creating an unbending three-dimensional structure (Das *et al*., 2019).The availability of various types of inorganic NPs and various chemical methods have shown that inorganic NPs can act as a novel system of drug delivery. Several important issues should be considered before using these inorganic NPs in clinical trials. The first important aspect that needs to be considered is the biocompatibility of the selected inorganic nanosystems. Unlike organic NPs, the clinical trials of inorganic NPs are difficult to do due to a lack of data regarding biosafety and toxicity while carrying out these experiments *in vivo*, and the excretion routes and assessment of toxicity are not well defined. The conventional inorganic-based nanosystem allowed different types of polygenic and monogenic diseases (Sharma and Paul, 2020). The NPs of the inorganic category have three major types: metallic (MNPs), quantum dots (QDs) and metal oxide NPs (MONPs) with MNPs being the focus of this study.

Magnetic inorganic NPs includes gold, copper, silver and palladium types, which have high stability that has been proven in various tumour conditions and they are used as biosensing agents (Vallabani*et al,* 2019). Oxides of silica, zinc, titania and zirconia have high stability and anti-oxidant catalytic actions that make them useful for the medical preparation of implants, bio-imaging and delivery of drugs. Metallic NPs are prepared from metal precursors and they possess a somewhat different property to alkali and noble metals, such as CuNPs and AgNPs. They have a broad absorption band in the visible zone of the electromagnetic spectrum. Metallic NPs are used in various important medical applications such as delivering drugs to areas that are difficult to reach. The particles are also used in the treatment of cancer and other lethal diseases (Xu*et al*, 2022).

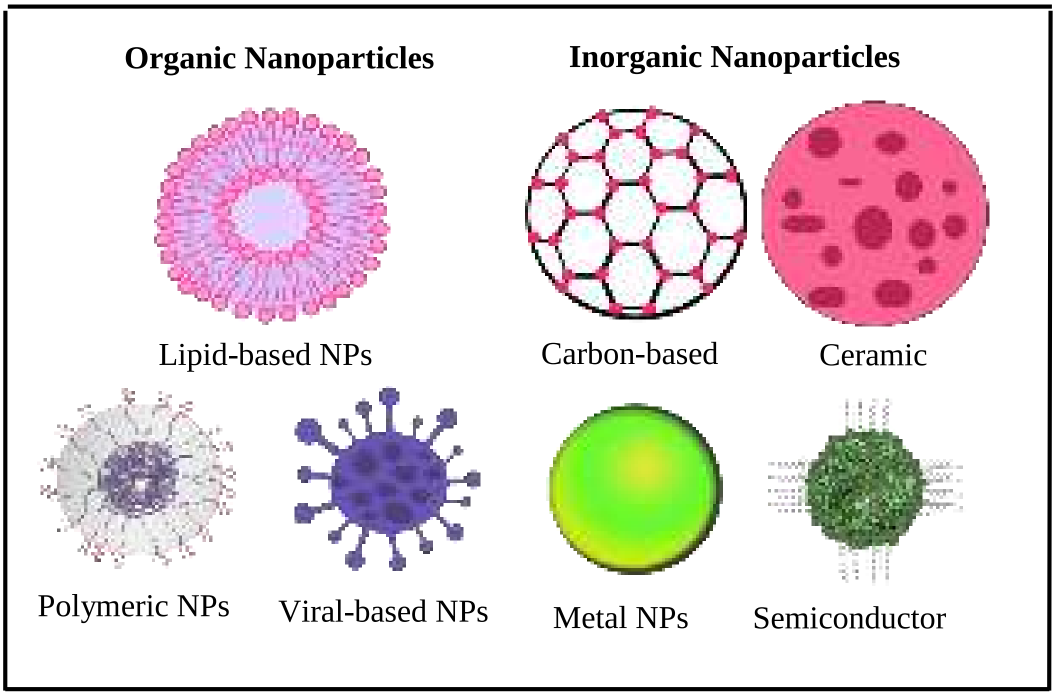

Figure 1: Classification of nanoparticles

Synthesis of Nanoparticles

Different methods can be used to synthesize NPs, but these methods are broadly divided into two main classes which are the Bottom-up approach and the Top-down approach as shown in Figure 2. These approaches can further be divided into various classes based on the operation, reaction condition, and adopted protocols.

Bottom-up approach

This approach is also called “building-up synthesis” since it is used in reverse as NPs are formed from nearly simpler substances. Examples of this synthesis as shown in Figure 2, are sedimentation and reduction techniques. It involves Sol-gel, green synthesis, spinning, and biochemical synthesis. Alizarin and titanium isopropoxide precursors were used to synthesize the photoactive composite for photocatalytic degradation of methylene blue. Alizarin was chosen as it gives a strong binding volume with TiO_2 through their axial hydroxyl thermal groups. The anatase formed was confirmed by an X-ray diffraction (XRD) pattern. More recently, the solvent-exchange method is used to attain maximumly sized low-density lipoprotein (LDL) NPs for medical cancer drug delivery. In this process, nuclear ion is the bottom approach followed by growth which is the “up” approach (Abid*et al*., 2022).

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Top-down Approach

In this synthesis, a destructive approach is used, starting from larger molecules, which break down into smaller units which are transformed into suitable NPs. Instances of this synthesis are grinding/milling, Chemical Vapor Decomposition (CVD), Physical Vapor Decomposition (PVD), and other decomposition methods (Abid*et al*., 2022). This approach is used for coconut shell (CS) NPs synthesis. The milling method was used for this approach and the raw CS powders were lightly milled at different time intervals, with the help of ceramic balls and a popular planetary mill. They showed the outcome of milling time on the general size of the NPs through various characteristics techniques. It was reported as time increases, the NPs crystalline size decreases, as calculated by the Scherer equation. They also realized that with each hour gain, the brownish colour faded away due to the size decrease of the NPs. (Bello *et al*., 2015).

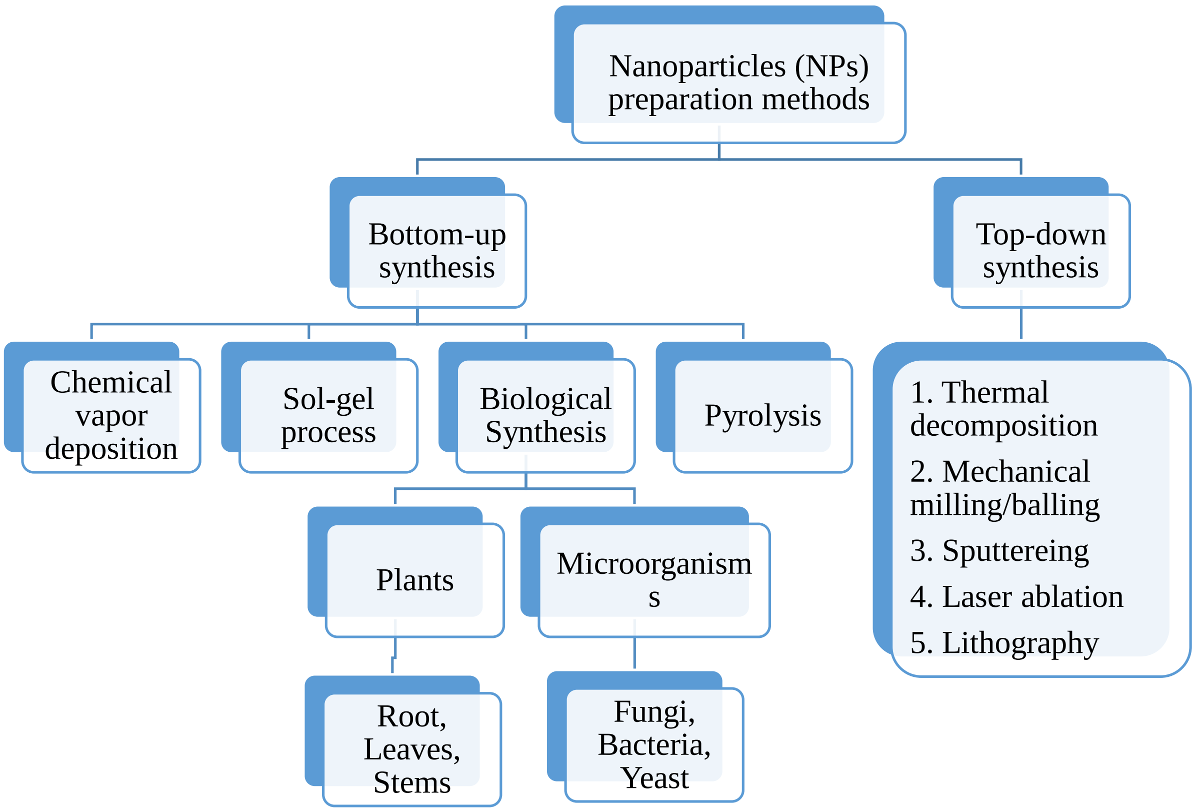

Figure 2: Typical synthetic method for NPs

Silver Nanoparticles (AgNPs)

Silver is a chemical element with the symbol Ag and atomic number fourth-seven (47). It is a soft, white, lustrous transition metal that reveals the highest electrical conductivity, thermal conductivity, and reflectivity of any metal. The metal is found in the earth's crust in the pure, free element form, as an ally with gold and other metals, and in minerals such as Argentine and chlorargyrite. Silver, in all its forms, has been historically used as an antimicrobial agent by itself or combined with other technologies (Fernandes*et al*., 2020). This metal has been researched to take advantage of its capacity to obstruct bacterial growth by including it as silver nitrate or silver sulfadiazine in creams and dressing to treat burns and ulcers, in food packaging to prevent contamination, in home appliances such as refrigerators and washing machines, and several industrial applications (Fernandes*et al*., 2018).

AgNPs have shown significant dimensions and higher surface (area-to-volume ratio) compared to silver in their bulk form. At this nano-scale, AgNPs show distinctive electrical, optical, and catalytic properties, which has led to the research and production. AgNPs have shown antimicrobial activity in opposition to a variety of transmittable and pathogenic microorganisms, including multidrug-resistant bacteria (Alayande*et al*., 2021). The therapeutic applications of AgNPs in terms of antiviral, antifungal, anticancer, and antibacterial properties have also been demonstrated. Presently, AgNPs are commercialized as antimicrobial agents in the pharmaceutical and cosmetic industries and are also used to fight against infections in various medical implants or bone cement (Ahmad e*tal*., 2020).

Green Synthesis of AgNPs

The green synthesis approach is the most suitable method to overcome the limitations associated with the physical and chemical methods (Akinsipo *et al*., 2022). This approach is a biogenic, simple, value-effective, dependable, and environmental-friendly technique for synthesizing AgNPs. Particular attention has been shown to the formation of AgNPs of defined size and shape. Multiple naturally occurring materials such as plant extract and microorganisms such as fungi, bacteria, and small biomolecules such as vitamins and amino acids are used as another source of reducing and capping agents.

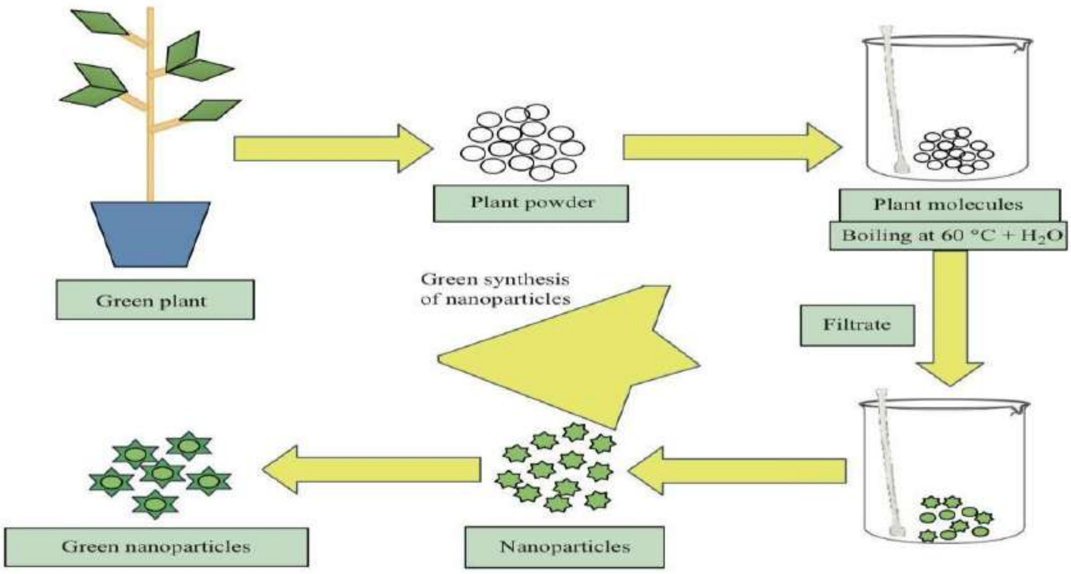

Figure 3: Green synthesis of nanoparticles

It is proposed that the bio-molecules, especially secondary metabolites in those extracts, could reduce the Ag ions (Figure 3). They consist of vitamins, polysaccharides, amino acids, proteins, enzymes, polyphenolics, flavonoids, and other secondary metabolites (Li *et al*., 2020; Goswami*et al*., 2021). Also, the protein found in the plant extracts plays a special role as a reducing agent for Ag^+ and as a size-controlling agent for the preparation of AgNPs. However, this method is associated with difficulties in terms of growth and culture maintenance. Synthesizing AgNPs using plant extracts offers different advantages in comparison to other green synthesis methods because plants are eco-friendly and easy to handle. Therefore, it offers energy efficiency, low toxicity, high yield, time consciousness, cost-effectiveness, and availability.

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Biomedical applications of green-synthesized silver nanoparticles

Due to different properties, AgNPs have been generally used in household utensils, food storage, and the healthcare industry for environmental and biological applications. The present review highlights different biological properties of AgNPs, with emphasis on its and antimicrobial, antidiabetic, anticancer, antioxidant, potential of AgNPs (HabeebRahuman *et al*., 2022).

Anti-bacterial Activity

AgNPs have a destructive action on the bacterial cell wall by inhibiting the cell respiratory chain and cell nucleic acid (DNA or RNA). AgNPs have been developed as an anti-microbial agent against Multi drug resistant (MDR) bacteria. Due to their large surface area to volume ratio and unique chemical and physical properties, the surface area to volume ratio is high as the particle size decreases (Balachandar *et al.,* 2022). Due to microbial resistance to antibiotics caused by mutation, discoveries of anti-bacterial products are desperately needed. AgNPs have four known anti-bacterial properties, including adhesion to the microorganisms cell membrane; Penetration of AgNPs into cells, which disrupts bio-molecules and intra-cellular damage; Induces cellular toxicity by generating reactive oxygen species (ROS), which causes oxidative stress in cells; Disruption of cell signal transduction pathways which causes oxidative stress (Alayande *et al*., 2021).

Bergal*et al.,* (2022) synthesized olive leaf (OL) and green tea leaf (GTL) extract with a green synthesis approach to compare and evaluate the characteristic antibacterial activity of synthesized AgNPs. The formation of AgNPs was observed by the change in colour of the reaction medium from white to dark brown and significantly increases in the basic environment with the temperature change. The antibacterial activity of synthesized AgNPs was compared with that of aqueous OL and GTL by agar well diffusion method. The inhibition zone for *E. coli* bacteria increased from 7 to 11 mm in GTL-synthesized AgNPs, and increase from 9 to 10 mm in OL- synthesized AgNPs. Thus, green synthesized AgNPs showed good antibacterial activity at lower concentrations. Another research showed the preparation of AgNPs using different saccharides and potent broad-spectrum bactericidal activity against gram-positive and gram-negative bacteria. The obvious result of this research was that the prepared AgNPs were active against multi-resistant bacteria strains such as staphylococcus aureus (Sathiyaseelan *et al*., 2020).

Antifungal Activity

The dominant group of pathogens in cereal crops is fungi which are responsible for approximately 80% of plant infections. Fusarium fungi are considered to be one of the most toxinogenic microorganisms in the world. The occurrence of these fungi is influenced by several factors, including agronomic practices and climatic conditions that cannot be controlled. For this reason, farmers are looking for alternative replacements for these products to eliminate or reduce plant pathogens (Pandey *et al*., 2018; Malandrakis *et al*., 2020; Gorczyca *et al*., 2021)

Hawar*et al.*, (2022) performed the green synthesis of AgNPs using *A. greacorum* and its anti-fungal activities were investigated. Scanning Electron Microscopy (SEM) image result indicated the spherical shape of AgNPs with a size range of 22-36 nm. Strong anti-fungal activities against candida species (*C.albicans*, *C.glabrata*, *C.parapsilosis*, *C. tropicales)* were observed. It was concluded that synthesized AgNPs from *A. graecorum* can be used as potential anti-fungal agents for various therapeutic applications. *Malvaparviflora* was used to biosynthesize silver nanoparticles. The biosynthesized AgNPs were spherical with an average diameter of 50-60nm. The study shows that the *M. parviflora* is a feasible and eco-friendly method and can be used to explore the development of ~~the~~ fungicide (Al- Otibi *et al.*, 2021). Dashora *et al.* (2022) investigated the antifungal activity of AgNPs synthesized with *Polyalthialongifolia*. UV-vis analysis showed a characteristic peak at 435 nm corresponding to surface plasmonic resonance. The biosynthesized NPs revealed a highly effective potential against plant pathogenic fungi.Beigoli*et al*. (2021) also used *aloe vera* plant extracts for antifungal activities. The study shows that *aloe vera*leaves can be used for fabricating and healthcare products supporting cell viability.

Antiviral Activity

Viral infections are a frequent worldwide issue, and it is getting worst almost every day. Therefore, the evolution of antiviral agents is a compulsory request of the day. Viruses, in addition to the coronavirus, grow and multiply rapidly, causing life-threatening illnesses such as HIV, influenza virus, Nipah virus, ebola virus and herpes virus (Rai, 2016). AgNPs are believed to be an effective and potent pharmacological agent with antiviral action. AgNPs play a special role due to their antiviral potential and can inhibit the growth and credibility of viruses AgNPs showed perfect activity against *hepatitis B* virus (HBV) and human immunodeficiency virus (HIV), as concluded by reported research (Verma and Mehashwari, 2019; Terrumieks *et al*., 2020; Zyildiz *et al*., 2021). However, the antiviral mechanism of AgNPs remains unknown A reported study related to the antiviral action of AgNPs has proven that they can inhibit the viability of viruses, however, antiviral therapies rely heavily on understanding the mechanism of AgNPs. AgNPs bind with the glycoprotein of the virus and then adhere to the genome and cellular particles, thereby blocking the viral replication process. It is also presented that the use of AgNPs greatly stopped the uplifting of the influenza virus in *Madin-Darbycanine* kidney cells (mammalian cell lines) and reduced vital titer in lung tissues (Trefry and Wooley, 2013). In a further study, treatment of AgNPs for 24 hours broadly shrunk the concentration of virus, prevalence of infection, and severity of yellow mosaic virus infections (Galdiero *et al*., 2011).

Antioxidant Potential of AgNPs

Many researchers studied the free radical scavenging activity of plant extract-mediated synthesized silver nanoparticles at various times. NPs formed using plant extracts have enhanced antioxidant activity and it may be owing to the excellent absorption of antioxidants from plant extracts on the surface of nanoparticles. The antioxidant properties of a silver nanosystem obtained from plants are hugely beneficial in the cure of disease. Hence, AgNPs acquired from extracts of plants were reported to have high antioxidant activity (Keshari*et al.*, 2020). Gecer (2021) synthesized green AgNPs*using Salvia Aeothiopis L.* The AgNPs synthesized from *S.aethiopis* revealed a high antioxidant activity.

Antidiabetic Activity

Nguyen *et al.* (2022) conducted research on *Azadirachitaindica* as an excellent and pharmaceutically valuable and phytochemical-enriched traditional medicinal plant. The purpose of the research was to access the ability of *A. indica* to synthesize AgNPs as well as investigate its anti-diabetic activity. The obtained result revealed that the aqueous kernel extract of *A.indica* can successfully create the AgNPs which was confirmed on characterization. The obtained results also revealed the number of the functional groups which belong to the pharmaceutically valuable phytochemical, acting as a reducing, capping and stabilizing agent on AgNPs synthesis. Meanwhile, the kernel-synthesized AgNPs showed a reasonable antidiabetic activity (73.5 %) at 100 μgmL^{-1} in comparison to the antidiabetic (87.9 %).

Anticancer Activity of AgNPs

Various researchers have reported the role of AgNPs in cancer diagnosis, their cytotoxicity, and their potential as carrier systems for cancer treatment. With their optical properties, high conductivity and small size, AgNPs have

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

demonstrated an essential role in enhancing signals and sensitivity in various biosensing platforms. Furthermore, AgNPs also can be used directly or developed as a drug delivery system for cancer treatment. Many studies investigated *in vitro* anticancer effects of chemically-synthesized AgNPs on both human and animal cancer cell lines. In contrast, various studies have also shown that chemically synthesized AgNPs displayed toxicity against normal cell lines, although they exhibited significant anticancer effects (Kummara *et al*., 2016; Boomi *et al*., 2019). Recently, the anticancer activities of Cuminumcyminum L. (Cumin) seed extract, chemically synthesized silver nanoparticles (AgNPs) and biosynthesized silver nanoparticles (Bio-AgNPs) from Cumin seeds on human breast adenocarcinoma cell line (MCF-7) and human breast adenocarcinoma metastatic cell line (AU565) were reported. From the results obtained, Cumin extract showed no inhibitory effects against AU565 cells. On the other hand, AgNPs and Bio-AgNPs displayed considerable anticancer activities on both cell lines (Dinparvar *et al*., 2020). Consequently, current anticancer research has been devoted to the discovery of novel transition metal compounds. While silver was initially investigated because of its advantageous antimicrobial activity, there has been a recent interest in its anticancer function.

Table 1: Some biomedical applications of green-synthesized AgNPs

S/N	Plant name/ part	Possible biomolecule involved	Application	References
1.	*Acacia nilotica* (bark)	Proteins and phenolic compounds	Antibacterial activity	Arya *et al*., 2019
2.	*Embeliaribes* (berry)	Hydroxyl, carboxyl, and aliphatic amines	Anticancer	Jagtap*et al*., 2022
3.	*Acalyphaindica* (plant)	Polyphenols, and alkaloids	Antifungal	Zarowska*et al*., 2019.
4.	*Cassia angustifolia* (flowers)	Phenols, carbonyls, nitro compound,	Antioxidant activity	Bharathi&Bhuvaneshwari, 2019
5.	*Aloe vera* (leaf)	Flavonones and terpenoids	Antibacterial	Buranje*et al*., 2021
6.	*Madhucalongifolia* (leaf)	Hirustrin, bilobalide, myricitrin, and esculin	Anticancer activity against breast cancer cell line	Sarkar *et al*., 2018
7.	*Tinosporacordifolia* (leaves)	Alkanes, lipids, and proteins.	Antioxidant activity	Selvan*et al*., 2017
8.	*Phoenix dactyliferia* (root hair)	Alkenes, alcohols, esters, carboxylic acid, esters.	Antifungal activity	Oves*et al*., 2018

CONCLUSION AND RECOMMENDATION

The review describes silver nanoparticles as interesting metal nanoparticles that possess unique characteristics and numerous therapeutic potential. The review further identifies the different synthetic approaches used in the synthesis of AgNPs while producing detailed information about green synthetic approach. Green biosynthesis of silver nanoparticles mediated plant extracts has numerous advantages over other methods because they are environment-friendly, cost-effective and highly suitable for the production of nanoparticles free of toxic contaminants required in bioapplications. In addition, this study highlighted the roles of AgNPs in various biomedical applications. Several reports on the biological activities of AgNPs including antibacterial, antifungal, antiviral, antioxidant, antidiabetic and anticancer were reviewed. From this review, it can be concluded that the green biosynthesized silver nanoparticles using plant extract are more beneficial biologically because plant materials are easy to handle, safe, widely distributed, and readily available. This research can serve as an interesting piece for a basic understanding of nanotechnology and green synthesis of nanoparticles. This research will further place researchers abreast of issues or challenges in their translational to clinical practice and while exploring the prospects that nanomedicine offers in the development of personalized and improved healthcare for mankind.

REFERENCES

Abbasi, E.,Aval, F., Akbarzadan, A., Mhani, M., Nasrabadi, T., Joo, W., Hanifehpour, Y., NeijatKoshki, K. and PasheelAsl, R. (2014)Dendrimers Synthesis, Application and Properties. *Nanoscale Research Letter*. 9(1): 247.https://doi.org/10.1010.1186/1556-276X-9-247.

Abid, N., Aqib Muhammad Khan, A. M., Sara ShujaitKainat, S. S., Muhammad Ikram, I., Imran, M., Haider, J., Khan, M., Khan, Q. and Maqbool, M. (2022) Synthesis of nanomaterials using various top-down and bottom-up approaches, influencing factors, advantages, and disadvantages: A review, *Adv. Colloid Interface Sci*. 300:102597, https://doi.org/10.1016/j.cis.2021.102597

Ahmad, A. (2020) Silver nanoparticles: synthesis, characterisation and biomedical applications. *Open Life Sciences*, 15(1): 819-839. https://doi.org/10.1515/biol-2020-0094

Akbarzadeh, A., RezaeiSardabady, R., Davaran, S., Joo, W., Zarghami, N., Hanifehpour, Y., Samuel, M. and NejatiKoshki, K. (2013) Liposomes Classification, Preparation and Application. *Nano Scale Research Letter*. 8(1):102. https://doi: 10.1186/1556-276X-8-102.

Akinsipo, O. B., Mustapha, T. O. and Adams, N. A. (2022) Biosynthesis And Characterization of Silver Nanoparticles using the Aqueous Extract of Acanthus Montanus Leaves Extract.*JCSN*, 47(2), https://doi.org/10.46602/jcsn.v47i2.717

Alayande, S. O., Akinsiku, A. A., Akinsipo, O. B., Ogunjimi, E. O. and Dare, E. O. (2021) Green synthesized silver nanoparticles and its therapeutic application In Biosynthesized Nanomaterials, Sandeep Kumar Verma, Ashok Kumar DasEds, Chapter 15, *Comprehensive Analytic Chemistry*. A Publication of Elsevier, 94: 585-611. https://doi.org/10.1016/bs.coac.2021.01.009.

Al-Otibi, F., Perveen, K., Al-Saif, N. A.,Alharbi, R. I., Bokhari, N., Albasher, G., Rana, M., Al-Otaibi, R. M. and Al-Mosa, M. A. (2021) Biosynthesis of silver nanoparticles using Malvaparviflora and their antifungal activity.*Saudi Journal of Biological Sciences*, 28(4), 2229-2235. https://doi.org/10.1016/j.sjbs.2021.01.012.

Amini, S. (2019) Preparation of Antimicrobial Metallic Nanoparticles with Bioactive Compounds. *Mater SciEng C Mater*

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

BiolAppl.103:109809. https://doi.org/doi:10.1016/j.msec.2019.109809.

Arya, G., Kumari, R., Pundir, R., Chatterjee, S., Gupta, N., Kumar, A., Chandra, R. andNimesh, S. (2019) Versatile biomedical potential of biosynthesized silver nanoparticles from Acacia nilotica bark. *J Appl Biomed*.17(2):115-124. https://doi.org/doi:10.32725/jab.2019.010.

Balachandar, R.,Navaneethan, R., Biruntha, M., Kumar, K., Kumar, A., Govarthanan, M. andKarmegam, N. (2022) Antibacterial activity of silver nanoparticles phytosynthesized from Glochidioncandolleanum leaves, Materials *Letters*, 311:131572, https://doi.org/doi.org/10.1016/j.matlet.2021.131572.

Beigoli, S., Hekmat, A., Farzanegan, F. *et al*. (2021) Green synthesis of amorphous calcium phosphate nanopowders using *Aloe Vera* plant extract and assessment of their cytotoxicity and antimicrobial activities. *J Sol-Gel SciTechnol* **98**, 508–516. https://doi.org/10.1007/s10971-021-05515-z

Bergal, A., Matar, G. H. andAndaç, M. (2022) Olive and green tea leaf extracts mediated green synthesis of silver nanoparticles (AgNPs): comparison investigation on characterizations and antibacterial activity. *BioNanoSci.* **12**, 307–321. https://doi.org/10.1007/s12668-022-00958-2

Bello, S. A., Agunsoye, J. O. and Hassan, S. B. (2015) Synthesis of coconut shellnanoparticles via a top-down approach: assessment of milling duration on the particlesizes and morphologies of coconut shell nanoparticles. Mater. *Lett*. 159:514-519.

Boomi, P., Poorani,G.P., Palanisamy, S., Selvam, S., Ramanathan, G., Ravikumar, S., Barabadi, H., Prabu,H.G., Jeyakanthan, J. andSaravanan, M. (2019) Evaluation of antibacterial and anticancer potential of polyaniline-bimetal nanocomposites synthesized from chemical reduction method. *Journal of Cluster Science*; 30(3), 715-726. 27.

Burange, P. J., Tawar, M. G. andBairagi, R. A. (2021) Synthesis of silver nanoparticles byusing *Aloe vera* and *Thujaorientalis* leaves extract and their biological activity: a comprehensive review. *Bull Natl Res Cent* 45: 181. https://doi.org/10.1186/s42269-021-00639-2.

Christophe, H. and Bilal, H. A. (2021) Plant-based green synthesis of nanoparticles: production, characterization, and applications. Biomolecules, 12(1), https://doi.org/31.10.3390/biom12010031.

Das A., Kamle, M., Bharti, A. and Kumar, P. (2019) Nanotechnology an and its Application in Environment Remediation: *An Overview*. 32, 227-237.

Dashora, A., Rathore, K., Raj, S. and Sharma, K. (2022) Synthesis of silver nanoparticles employing *Polyalthia longifolia* leaf extract and their *in vitro* antifungal activity against phytopathogen. *BiochemBiophys Rep*. 31:101320, https://doi.org/doi:10.1016/j.bbrep.2022.101320.

Dinparvar, S., Bagirova, M., Allahverdiyev, A. M, Abamor, E. S., Safarov, T., Aydogdu, M. andAktas, D. (2020)A nanotechnology-based new approach in the treatment of breast cancer: Biosynthesized silver nanoparticles using Cuminumcyminum L. seed extract. *J PhotochemPhotobiol B*. 208:111902. https://doi.org/doi: 10.1016/j.jphotobiol.2020.111902. Epu

Fernandes, I. J., Aroche, A. F. andSchuck, A. (2020). Silver nanoparticle conductive inks: synthesis, characterization, and fabrication of inkjet-printed flexible electrodes. *Sci Rep* **10**, 8878 (2020). https://doi.org/10.1038/s41598-020-65698-3

Galdiero, S., Falanga, A., Vitiello, M., Cantisani, M., Marra, V. andGaldiero, M. (2011) Silver nanoparticles as potential antiviral agents. Molecules.

https://doi.org/doi:10.3390/molecules 16108894.

Gecer, E. N. (2021) Green Synthesis of Silver Nanoparticles from *Salvia aethiopis* L. and Their Antioxidant Activity. *Journal of Inorganic and Organometallic Polymers and materials* 31:4402–4409. https://doi.org/10.1007/s10904-021-02057-3.

Gorczyca, A., Pociecha, E. and Matras, E. (2021) Nanotechnology in Agriculture the food sector and remediation prospects relation and constraints, in environmental pollution andremediation. *Environmental and Microbial Biotechnology* (ed. Prasad, R.) 1-34.

Goswami, T., Bheemaraju, A., Sharma, A. K. and Bhandari, S. (2021) Perylenetetracarboxylic acid-incorporated silver nano cluster for cost-effective visible-light driven photo catalysis and catalytic reduction. *CollidPolym. Sci*., 299:925-936.

Griffin, S., Masood, M. I., Nasim, M. J., Safraz, M., Ebokaiwe, A.P., Schafer, K. H. Kech, C. M. and Jacob, C. (2018) Natural Nanoparticle; A Particular Matter Inspired by Nature Antioxidant (Basel), 7(1):3.

HabeebRahuman, H. B., Dhandapani, R., Narayanan, S., Palanivel, V., Paramasivam, R., Subbarayalu, R., Thangavelu, S. and Muthupandian, S. (2022) Medicinal plants mediated the green synthesis of silver nanoparticles and their biomedical applications. *IETNanobiotechnol.*, 16(4):115-144. https://doi.org/doi: 10.1049/nbt2.12078.

Hawar, S. N., Al-Shmgani, H. S., Al-Kubaisi, Z. A., Sulaiman, G. M., Dewir, Y. H. and Rikisahedew, J. J. (2022) Green Synthesis of Silver Nanoparticles from Alhagigraecorum Leaf Extract and Evaluation of Their Cytotoxicity and Antifungal Activity, J. Nanomaterials, 1058119, 8 pages, https://doi.org/doi.org/10.1155/2022/1058119.

Jagtap, R. R., Garud, A., Puranik, S. S., Rudrapal, M., Ansari, M. A., Alomary, M. N., Alshamrani, M., Salawi, A., Almoshari, Y., Khan, J. and Warude, B. (2022) Biofabrication of Silver Nanoparticles (AgNPs) Using Embelin for Effective Therapeutic Management of Lung Cancer. *Front Nutr*. 9:960674. https://doi.org/doi:10.3389/fnut.2022.960674.

Keshari, A. K., Srivastava, R., Singh, P., Yadav, V. B. andNath, G. (2020). Antioxidant and antibacterial activity of silver nanoparticles synthesized by Cestrum nocturnum. *J Ayurveda Integr Med*. 11(1):37-44. https://doi.org/doi:10.1016/j.jaim.2017.11.003.

Kumar, H., Venkatesh, N., Bhowmik, H. and Kailua A, A. (2018) Metallic Nanoparticles, A Review, Biomedical, *Journal of Scientific and Technical Research* (4), 3765-3775.

Kummara, S., Patil, M. B. and Uriah, T. (2016) Synthesis, characterization, biocompatible andAnticancer activity of green and chemically synthesized silver nanoparticles. A comparative study. *Biomed Pharmacother*. 2016; 84: 10-21. 28.

Lan Chi, N. T., Narayanan, M., Chinnathambi, A., Govindasamy, C., Subramani, B.,Brindhadevi, K., Pimpimon, T. andPikulkaew, S. (2022) Fabrication, characterization, anti-inflammatory, and anti-diabetic activity of silver nanoparticles synthesized from Azadirachtaindica kernel aqueous extract. *Environ Res*. 208:112684. https://doi.org/doi:10.1016/j.envres.2022.112684.

Li, B. J., Li, S., Ma, B. R., Jing, Y., Zhang, Z. M., Li, Z. J. and Zhao, S. Y. (2020) Progressin the preparation of silver nanometer antibacterial material. *Mater. Sci. Forum* 2020, 996:76-81.

Malandrakis, A. A., Kavroulakis, N. and Chrysikopoulos, C. V. (2020) Synergy between Cu-NPs and fungicides against Botrytis anerea. *Sci Total Environ* 703,135557.

Scientia Africana, Vol. 23 (No. 3), August, 2024. Pp 11-24
© Faculty of Science, University of Port Harcourt, Printed in Nigeria *ISSN 1118 – 1931*

Mattew, H., Melisa, D., Maria, D and Anisha, G., (2021) Green synthesis of nanomaterials, *Nanomaterials*(Basel), 11(8), 2130, https://doi.org/10.3390/nano11082130.

Mishra, A. and Sardar, M. (2012) Alpha Amylase Mediated Synthesis of Silver NPs. *Advanced Materials,* 4:143-146.

Mohd, S. M., Noor, S. A., Mohd, A. N. and Annie, M. M. (2012) Effect of cationic surfactant in Sol-gel synthesis of nano sized magnesium oxide. *APCDEE Procedia*, 3:93-98.

Muhammed, I. D. (2022)A comparative study of research and development related tonanotechnology in Egypt, Nigeria and South Africa, Technology in Society, 68:101888.

Mustapha, T., Misni, N., Ithnin, N. R., Daskum, A. M. andUnyah, N. Z. (2022). A Review onPlants and Microorganisms Mediated Synthesis of Silver Nanoparticles, Role of Plants, Metabolites and Applications. *Int J Environ Res Public Health*,19(2):674. https://doi.org/doi:10.3390/ijerph19020674.

Naymih, N. (2019) Green Synthesis Characterization and Application of Silver & Gold Nanoparticles, Chapter 6, In Green Synthesis, Characterization and Application of Nanoparticles, *Micro and Nanotechnologies*, Pp.111-135.

Nicolopoulou-Stamati, P., Maipas, S., Kotampasi, C., Stamatis, P. and Hen, L. (2016) Chemical pesticides and human health, the urgent need for a new concept in agriculture. *Front public health* 4,1-8.

Njud, S. A. and Afnan, I. F. (2022) Green synthesis of silver nanoparticles using medicinal plants; characterization and application.*JRRAS*, 15(3): 109-114.

Oves, M., Aslam, M., Rauf, M., Qayyum, S., Qari, H. A., Khan, M., Alam, M., Tabrez, S., Pugazhendhi, A. and Ismail, I. M. I. (2018) Antimicrobial and anticancer activities of silver nanoparticles synthesized from the root hair extract of Phoenix dactylifera. *Materials Science and Engineering: C*, 89: 429-443, https://doi.org/10.1016/j.msec.2018.03.035.

Pandey, S. G., Kumar, R., Mishra, G. and Raja, R. R. (2018) Nanopesticides. Opportunities in crop protection and associated environmental risks Proc. *Nat. Acad sci. India sect B: Biol. Sci*. 88(4) 1287-1308.

Paul, W. and Sharma, C. P. (2020) Inorganic nanoparticles for targeted drug delivery, Chapter 13, Chandra P. Sharma Eds In Woodhead Publishing Series in Biomaterials,*Biointegration of Medical Implant Materials* (Second Edition),Woodhead Publishing,Pages 333-373, https://doi.org/10.1016/B978-0-08-102680-9.00013-5.

Rai, M., Deshmukh, S. D., Ingle, A. P., Gupta, I. R., Galdiero, M. andGaldiero, S. (2016) Metal nanoparticles: The protective nanoshield against virus infection, Critical Reviews in *Microbiology,* 42:1, 46-56, DOI: 10.3109/1040841X.2013.879849.

Salem, S. S. andFouda, A. (2021) Green Synthesis of Metallic Nanoparticles and Their Prospective Biotechnological Applications: an Overview. *Biological Trace Element Research*, 199, 344–370. https://doi.org/10.1007/s12011-020-02138-3.

Sarkar, M. K., VellingiriVadivel, V., Charan Raja, M. R. and Mahapatra, S. K. (2018) Potentialanti-proliferative activity of AgNPs synthesized using M. longifolia in 4T1 cell line through ROS generation and cell membrane damage. *Journal of Photochemistry and Photobiology*, 186:160-168, https://doi.org/10.1016/j.jphotobiol.2018.07.014.

Sathiyaseelan, A., Saravanakumar, K., Mariadoss, A. V. A. and Wang, M. H. (2020) Biocompatible fungal chi Tosin encapsulated photogenic silver nanoparticles enhanced antidiabetes, antioxidant, and antibacterial activity. *Int. J. Biol. Macromol*. 2020, 153, 63-71. https://doi:10.1016/j.ijbiomac.2020.02.291.

Selvam, K., Sudhakar, C., Govarthanan, M., Thiyagarajan, P., Sengottaiyan, A., BalakrishnanSenthilkumar, B. andSelvankumar, T. (2017) Eco-friendly biosynthesis and characterization of silver nanoparticles using Tinosporacordifolia (Thunb.) Miers and evaluate its antibacterial, antioxidant potential. *Journal of Radiation Research and Applied Sciences*, 10(1): 6-12, https://doi.org/10.1016/j.jrras.2016.02.005.

Terrumieks, E., Balchev, I., Ghalot, R. S. and Lazov, L. (2020) Antibacterial and antiviral effects of silver nanoparticles in medicine against Covid-19. A review. *Laser ablation phys*., 31, 013001.

Trefry, J. C. and Wooley, D. P., (2013). Silver nanoparticles inhibit vaccinia virus infection by preventing viral entry through a macropinocytosis-dependent mechanism. *J. Biomed. Nanotechnol*. 9: 1624-1635.

Vallabani, N. V. S., Singh, S. and Karakoti, A. S. (2019) Magnetic Nanoparticles: Current Trends and Future Aspects in Diagnostics and Nanomedicine. *Curr Drug Metab. 2*0(6):457-472. https://doi.org/doi: 10.2174/1389200220666181122124458.

Verma, P. and Maheshwari, S. K. (2019). Applications of Silver nanoparticles in diverse sectors. *Int. J. Nano Dimens.*, 10 (1): 18-36.

Vorobyova, V., Skiba, M.,Shakun, A. S. and Nasiriya, S. V. (2019) Relationship Between the Inhibition and Antioxidant Properties of the Plant and Biomass Wastes Extract: A Review. *Int. J. Corros. Scale Inhib*. 8(2): 150–178.

Walia, S. and Acharya, A. (2018) Nanomaterials for Chemical and Biological Analysis and Detection, *J. Bionanosci*.12: 316-327.

Wang, J., Li, B., Qiu, L., Qiao, X. and Yang, H. (2022) Dendrimer-based drug delivery systems: history, challenges, and latest developments. *J. Biol. Eng.* 16 (18). https://doi.org/10.1186/s13036-022-00298-5

Xu, J. J., Zhang, W. C., Guo, Y. W., Chen, X. Y. and Zhang, Y. N. (2022) Metal nanoparticles as a promising technology in targeted cancer treatment. *Drug Deliv*. 29(1):664-678. https://doi.org/doi:10.1080/10717544.2022.2039804.

Xu, L., Wang, Y. Y., Huang, J., Chen, C. Y., Wang, Z. X. and Xie, H. (2020) Silver nanoparticles: *Synthesis, medical applications and biosafety, Theranostics*, 10(20): 8996-9031. doi:10.7150/thno.45413.

Ying, S., Guan, Z., Ofoegbu, P. C., Clubb, P., Rico, C., He, F. and Hong, J. (2022) Greensynthesis of nanoparticles: *Current developments and limitations, Environmental Technology and Innovation*, 26 ,https://doi.org/ doi.org/10.1016/j.eti.2022.102336.

Żarowska, B., Koźlecki, T., Piegza, M., Jaros-Koźlecka, K. and Robak, M. (2019) New Look onAntifungal Activity of Silver Nanoparticles (AgNPs). *Pol J Microbiol*. 68(4):515-525.https://doi.org/doi:10.33073/pjm-2019-051.

Zyildiz, F., Seydibeyoglu, E. A. andSeydibeyoglu, N. O., (2021)The role of nanotechnology for antimicrobial agents. In coronalogy: *Muilti-disciplinary Academic Analysis in perspective of Covid-19*: Sciendo: pp. 170-185.