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Review article

Biosynthesis of Silver Nanoparticles and Their Applications

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ABSTRACT

Recent developments in nanotechnology and nanoscience have improved methods for treating, preventing, and diagnosing a wide range of illnesses in many parts of living beings. Silver nanoparticles (Ag NPs) are among the most significant and intriguing metallic nanoparticles employed in several biological applications. To create Ag NPs, biomolecules from diverse microbial species and plant components have been researched as possible agents. Due to their physical orientation characteristics, and small size, these Ag NPs are widely employed and are said to have an impact on the performance of any other material that comes into touch with them. In addition, straightforward biological, physical, and chemical methods may be used to create Ag NPs. Due to their enhanced responsiveness to environmentally friendly technology for quantifiable synthesis, several developed nations have seen significant growth in the biosynthesis of Ag NPs. The biological method, however, is the approach to preparation that is most in demand since it is quicker, safer, less expensive, and more environmentally friendly than other techniques. In addition, the importance of Ag NPs is extensively examined in light of their numerous bioapplications, including those for antifungal, anti-inflammatory, antibacterial, Antiviral activity, Catalytic Activity, and anticancer medicines.

1. Introduction

A significant turning point in the history of the cosmos may be seen in nanotechnology. The limitless curiosity and intellect of people have given rise to ground-breaking innovations like artificial intelligence, smartphones, the internet, rocket science, and in vitro fertilization procedures, which also raise a number of moral questions. Because of this, nanotechnology is a field of study that was originally regarded with scepticism. By building, synthesizing, and manipulating bulk molecules and particles at nanoscale dimensions, material science has turned to nanotechnology as a critical tool to overcome these constraints. Nanoparticles are created items that range in size from 1 to 100 nm. The many anomalous features of metal nanoparticles have led to their widespread uses. Since they are a bulk object's smallest particle, nanoparticles exhibit improved characteristics since additional atoms are found on their surfaces and have less cohesion than the bulk material [1]. One of the most exciting industrial phenomena of the contemporary period, nanotechnology has opened new prospects in a variety of fields like healthcare, the environment, food packaging, animal husbandry, and agriculture. With an expanding spectrum of applications, it provides a new instrument for tackling the difficulties of making technology more environmentally friendly and sustainable [2].

There are two types of nanoparticles: inorganic and organic. Magnetic (Ni, Co), metallic (Au, Ag), and semi-conductor ($CaSO_4$, ZnO) kinds make up the majority of inorganic NPs, whilst carbon-based NPs like carbon nanotubes and quantum dots make up organic nanoparticles [3, 4]. Due to their peculiar properties, including their physical makeup, reactivity, and possible use in drug delivery, diagnostics, and research on antioxidants and microorganisms, metal nanoparticles are favorable to utilize. The structural and

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hyperfine characteristics of Al-doped SnO_2 NPs produced utilizing a polymer precursor method were examined by Aragon et al. [5]. In association with their bulk complements, metal nanoparticles exhibit improved shape, size, and surface area. The interest in silver nanoparticles has increased significantly as a result of the greater rate of commercialization, which accounts for 55.4%, or 313 out of 565, of all goods based on noble metal nanoparticles that are sold to consumers [6]. For antibacterial, anticoagulant, anticancer, orthopedic, and thrombolytic reasons as well as in medication delivery, medical devices, diagnostics, and sensing, etc., silver nanoparticles have been employed extensively. The catalytic activity, thermal and optical characteristics, thermal and chemical stability, and antibacterial activity of AgNPs all contribute to their significance [7].

The outstanding characteristics of biological molecules make them the best candidates for utilization in nanotechnology. To prepare the biological particles for the appropriate metal nanoparticle manufacturing, which has been shown to be dependable and ecologically safe, they go through highly regulated association processes [4, 8]. Many chemical and physical procedures have been used to produce metal NPs, but some of these procedures have downsides, including the use of risky solvents, the production of harmful by-products, and high energy demands. Therefore, it is imperative to enhance environmentally benign methods of producing metal NPs. It is crucial to advance environmentally friendly methods in physical synthesis so that they may be applied to biological systems [9].

Recently, a variety of synthesis techniques for green NPs with well-defined sizes, morphologies, and chemical compositions have been created, and their prospective requests in several cutting-edge technological domains have been researched [10, 11]. As a result, green synthesis techniques have been developed for the production of NPs employing a diversity of biological organisms, counting mold, yeast, algae, plant extracts, and bacteria. Additionally, Ag NPs have been employed commercially for a variation of coating applications, including electronics, pharmaceuticals, and regions with energy contact activities. The commercial uses of these NPs in the fields of medicinal and other medical sciences rely heavily on Ag NPs.

Additionally, Ag NPs are thought to be the greatest promising antibacterial agent due to their high bioactivity against bacteria, protozoa, fungus, and viruses [12]. It has been discovered that several microorganisms, like intra- and extracellular bacteria, fungi, plants, and yeasts, which have greater crop yields and cheaper production costs, are capable of producing NPs. In comparison to micro-sized silver ions, Ag NPs have an advanced surface area-to-volume ratio for interactions, which makes it easier for NPs to enter and destroy bacterial cells. This contributes to their high efficiency [13, 14]. The purpose of a short review is to open up new perspectives and investigate future applications of Ag NPs biosynthesis.

2. Synthesis of Ag NPs

2.1. Chemical methods

The most widely used technique for creating stable, colloidal dispersions of Ag NPs in organic or water-based solvents is chemical reduction. Citrate is the most often used reductant. Silver is reduced in aqueous solution, and colloidal silver ions of nanoscale are produced. Any colloidal dispersion must be stable, and dodecanethiol, a stabilizing agent, may do this by adhering to the surface and producing a protective coating. It can prevent the system's agglomeration and crystal formation. Small adjustments to the polymers' properties during the synthesis of Ag NPs cause significant modifications to the particles' shape, size, polydispersibility index, morphology, self-assembly, and zeta potential (Stability). Ag NPs and Au NPs are frequently made with polyethylene glycol (PEG) and the glycol derivatives polyvinyl pyrrolidone (PVP). In the manufacture of AuNPs, polyacrylamide is used both as a reducing and stabilizing agent [15]. Surfactants with functional groups like oils, amines, and acids have a substantial impact on the constancy of colloidal dispersion, which defends the system against coalesces, crystal formation, and agglomeration. Currently, silver hydrosols and saccharides, together with a reducing agent, are used to create Au NPs using the modified tollens technique, producing Ag NPs that are between 20 and 50 nm and 50 to 200 nm in size, respectively [16].

2.2.Physical methods

Evaporation and condensation play a significant role in the physical approach to Ag NP production. A temperature gradient is crucial for the appropriate rate of vapor cooling. Since there was no solvent employed in the physical process and a uniform distribution of particle size was carefully attained, any danger of solvent contamination was eliminated [17]. Production of high-concentration nanoscale NPs makes it simple to reach the minimal inhibitory concentration in toxicity investigations [18]. Additionally, metallic particles can be laser-ablated to create Ag NPs. When compared to other techniques for creating metal colloids, laser ablation technology has a considerable advantage due to the non-appearance of chemical reagents in solutions. As a result, using this approach, pure and unadulterated metal colloids may be created for use in other applications [19]. Numerous materials, including Au, Au, and Pb, among others, may be physically produced into NPs. There are many drawbacks to producing Ag NPs in a tube furnace, including the need for more room, high power requirements, quick temperature increases outside, etc. Ag NPs produced by laser ablation are highly dependent on the

liquid medium, ablation time, laser wavelength, laser pulse duration, and fluency. Ag NPs produced by laser ablation may be ejected with minimum power consumption, and particle size accurately relies on laser fluency. However, the interaction with the laser light has the greatest impact on the morphology, size, and shape of the Ag NPs. The surfactant coating also prevents the creation of NPs caused by laser ablation. When compared to solutions with lower surfactant concentrations, high surfactant concentration solutions produce smaller NPs. The lack of chemical reagents in solutions makes laser ablation superior to other traditional methods for producing metal colloids. As a result, this approach can yield pure colloids that are valuable for future applications [20].

2.3.Biological methods

A new tool for creating biological Ag NP synthesis is biotechnology. Additionally, magnetic NPs have excellent antibacterial potential because of their increased surface area, which may be used to treat increased microbial resistance to various antibiotics and medications [21]. With naturally available stabilizing, reducing, and capping agents, green chemistry is now a fast-expanding method used to produce Ag NPs without hazardous side effects [22]. It has been effectively shown that herbs and certain enzymes, proteins, microbes, bacteria, and fungus, among other things, work together to reduce metal ions during biological synthesis[23].

2.3.1.Synthesis of Ag NPs using bacteria, fungi

The Pseudomonas stutzeri AG259 strain, which was obtained from the soil of silver mines, was used to create the first bacterium capable of manufacturing silver NPs. Due to their resistance to the metal, some bacteria that can live in situations with high metal ion concentrations can also grow in those conditions.

Due to their capacity to release a lot of enzymes, fungi, and other microbes become better candidates for the synthesis of metal NPs with diverse sizes (**Table 1**). By using the dead biomass of the fungus Hypocrea lixii, Salvadori et al. [24] developed a novel, efficient, and environmentally friendly bioprocess for the production of nanomaterials.

The first steps in the biological manufacture of Ag NPs with sizes of 123–195 nm [25], 50–100 nm [26], and 20–80 nm[27] were taken using the fungus *Candida albicans* and *Pestaloptiopsis pauciseta*, respectively. Fungi, as opposed to bacteria, may produce more NPs due to their ability to release more protein, which increases the total amount of NPs produced [28]. It is also known that before fungi can make Ag NPs, Ag+ ions must be captured at the surface of their cells, where they are then reduced by enzymes unique to the fungus. Although the precise mechanism for the development of Ag NPs by fungus is not entirely understood, it is believed that the aforementioned occurrence is in charge of the process.

High-yielding output When compared to bacteria, fungus produce a bigger number of proteins that are directly responsible for the enhanced creation of Ag NPs [28]. The major cause of the higher production rate is the entry of silver ions into the fungal cell wall, which causes them to be reduced by fungal enzymes such as naphthoquinones and anthraquinones [29]. The primary drawback of employing microorganisms to create Ag NPs is that the process is much slower than that of using plant extracts. Therefore, a more logical option would be to create Ag NPs using plant extracts.

Table .1. The environmentally friendly creation of different-sized Ag NPs by bacteria and fungus.

Producer organism	Size (nm)	Ref.
Candida albicans	50-100	[26]
Trichoderma harzianum	19-63	[30]
Cunninghamella phaeospora	12.2	[31]
Fusarium sp.	12-20	[32]
Aspergillus clavatus	25-145	[33]
Fusarium solani	5-30	[34]
Aspergillus terreus	10-18	[35]
Aspergillus fumigatus	5-95	[33]
Nocardiopsis valliformis	5-50	[36]
Aspergillus niger	25-175	[33]
Aspergillus versicolor	15.5	[37]
Cyanobacteria aqueous	38-88	[31]

2.3.2. Synthesis of Ag NPs by plants

One of the most fascinating scientific fields in recent years has been nanoparticle creation, and interest in creating NPs using plant extracts has grown. The main advantages of plant-based extracts for the preparation of Ag NPs include their accessibility, safety, and nontoxicity in extreme circumstances. They also have an extensive variety of metabolites that can help reduce silver ions, are synthesized more quickly than microbes, and contain significant amounts of phytochemicals that can be used as reducing agents for the synthesis of Ag NPs (**Figure 1**). By sonicating extracts from sixteen commonly found plants, Ag NPs were produced in a green way [38]. When tested for their ability to inhibit the growth of bacteria like *E. coli*, *Salmonella paratyphi*, *S. aureus*, and *B. subtilis*, these NPs were found to have exceptional antibacterial activity. Moreover, Ag NPs have been efficiently shaped using *Chrysophyllum oliviforme* extracts by reducing aqueous silver nitrate [39]. Additionally, *Momordica charantia* leaf extracts were used in equal amounts as a stabilizer and reductant to create the Ag NPs in an environmentally friendly manner [40].

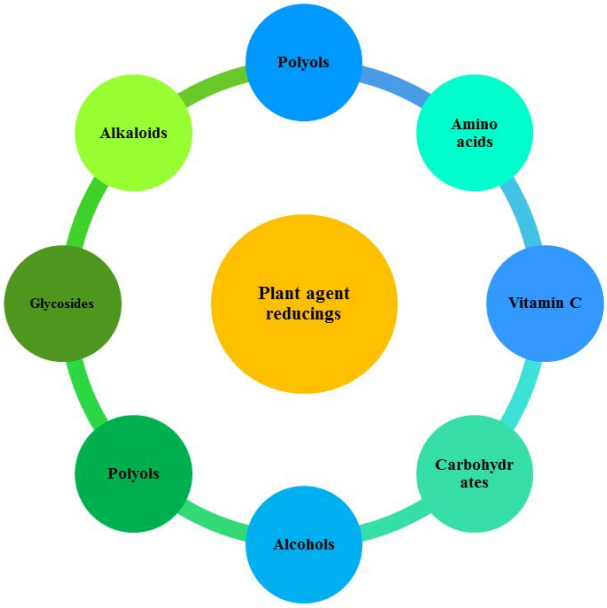

Figure.1. The bio-reductant phytochemicals[41].

3. Applications of Ag NPs

3.1.Antimicrobial activity

Numerous certified agencies, including the USFDA, USEPA, Korea's testing authority, and SIAA of the Japan Institute of Research have approved products made using silver NPs. Ag NPs containing silver sulfadiazine have antibacterial and antimicrobial potential, and they are utilized in medications and burns to prevent infections. Ag NPs are now used to expand the area of nanotechnology and are found in numerous consumer goods, such as deodorizing sprays and creams for acne vulgaris. The size, environmental factors (pH, size, tonic strength), capping agent, and environmental variables all affect how antimicrobial Ag NPs are. When Ag NPs are combined with ampicillin, amoxicillin, and chloramphenicol, antimicrobial activity improves synergistically; however, reports of antagonistic interactions between Ag NPs and amoxicillin or oxacillin antibiotics combined with Ag NPs have suggested improved therapeutic activity [42, 43]

3.1.1.Antiviral activity

Viruses are currently acknowledged as one of the major disease-causing factors in humans. Despite their blatant structural simplicity, viruses offer a serious threat in the face of deadly illnesses like the COVID-19-caused 2020 pandemic, Marburg virus, Ebola, HIV, and the Spanish flu [44]. The prevalence of resistant virus strains and the harmful side effects of prolonged usage continue to hinder the widespread use of effective antiviral medicines, making viral infections a serious threat to world health. It is, therefore, critical to provide secure and effective antiviral medication alternatives. Researchers are looking for novel antiviral therapeutics as a result of COVID-19's recent resurgence and resistance to current antiviral medications. As of May 2021, the SARS-CoV-2 pandemic had claimed more than 3.2 million lives globally. It started in December 2019. The ability of viruses to infect and attach to host cells depends on how well their surface components bind to ligands and proteins on the cell membrane. Therefore, preventing such binds should be the main focus of future antiviral medication development. Due to their unique chemical and physical characteristics, metal NPs have recently become key prospects for use as antiviral medicines; AgNPs are one such example. Microorganisms' resistance to these NPs can be decreased by AgNPs' extensive array of assault mechanisms against their targets [45].

Infectious disorders caused by viruses, including SARS-Cov, influenza A/H1N1, influenza A/H5N1, dengue virus, HBV, HIV, and novel encephalitis viruses, have been reported to be developing and reemerging more often in recent years. These viral infections have a high like lihood of developing into dangerously contagious illnesses [46].

As previously indicated, Ag-NPs have demonstrated excellent activity against bacteria and fungus.

Antiviral activity of Ag NPs has been shown to suppress HIV-1 at non-cytotoxic concentrations, though the mechanism behind this action is still not completely understood. The study from intranasal administration of Ag NPs in mice after infection with the H3N2 influenza virus revealed increased survival, minor pathologic lesions in lung disease, decreased lung viral titer levels, and a remarkable survival benefit, indicating that Ag NPs played a significant role in mice survival. Based on zeta potential and size, biologically produced Ag NPs reduced the survival of human para influenza virus type 3 and the herpes simplex virus (HSV) types 1 and 2. The action of vero cells with non-cytotoxic concentrations of Ag NPs (PPRV) significantly inhibited the replication of the paste des petits ruminant’s virus. The interaction of Ag NPs with the virion core is what causes the viral replication processes. Through direct contact, inhibited viral attachment, penetration, and subsequent dissemination, tannic acid-mediated production of different sizes of Ag NPs can reduce HSV-2 infectivity both in-vitro and in-vivo [20, 47].

According to research, the interaction between Ag-NPs and the virus only involves NPs of a size between 1 and 10 nm. Furthermore, it has been proposed that Ag-NPs and HIV-1 interact by preferentially adhering to the exposed sulfur-containing residues of the gp120 glycoprotein knobs, blocking the virus's attachment to host cells. Lara et al.[48] later demonstrated this method. According to the information in this article, Ag-NPs show anti-HIV effects at a very early stage of virus replication, most likely acting as an inhibitor of viral entry or a veridical agent. AgNPs act as

an actual agent against cell-free viruses (clinical isolates, laboratory strains, resistant strains, and tropical T and M strains) and cell-associated viruses by binding to gp120 in a manner that inhibits CD4-dependent virus association, fusion, and infection. Additionally, Ag-NPs block the HIV-1 life cycle during the post-entry stages.

A HepAD38 cell line was used as an infection model in separate research by Lu et al. [49] to examine the effects of Ag-NPs of various diameters (10, 50, and 800 nm) on the hepatitis B virus (HBV). Their research demonstrated that only Ag-NPs were capable of preventing the in vitro generation of HBV RNA and extracellular virions. Ag NPs conjugated with (N-vinyl2-pyrrolidone) (PVP), recombinant respiratory syncytial virus (RSV) fusion protein (F), and bovine serum albumin (BSA) are utilized by Sun et al. to investigate the prevention of RSV infection in HEp-2 cell culture[50]. The acquired results demonstrated that PVP-coated silver NPs prevented RSV infection by 44%, a substantial decrease when compared to other controls. These particles showed little toxicity to cells at low doses. It was determined that the PVP-coated Ag-NPs would bind to the G proteins on the surface of the RSV and prevent the virus from attaching to the HEp-2 cells, hence inhibiting viral infection. Ag NPs of various sizes and surface finishes were employed to evaluate the monkeypox virus. Preliminary results revealed that Ag NPs of about 10 nm inhibit MPV contagion in vitro, and Ag NPs of 25 nm and 55 nm show a significant ($P \leq 0.05$) dose-dependent effect of the test compound concentration on the mean number of plaque-forming units (PFU)[51].

De Gusseme et al. [52]produced the bio-Ag-NPs, also known as biogenic Ag^0, and later investigated the antiviral effects of both biogenic Ag0 and ionic Ag^+ on murine norovirus. Surprisingly, the acquired data revealed that only a little reduction in genomic copies was found in the disinfection experiment using ionic Ag^+. Genomic copies did not significantly decrease after exposure to biogenic Ag^0.

In contrast, the plaque tests showed that MNV-1's infectivity was totally blocked. The interaction of biogenic Ag^0 with (thiol groups in the) the MNV-1 capsid proteins, which makes the RNA accessible and renders the virus particle non-infectious, has been proposed as the inactivation mechanism of MNV-1. Smaller NPs might perhaps favor this interaction. More recently, Xiang et al. [53] looked into the inhibition of Ag NPs on the in vitro H1N1 influenza A virus. Their research showed that Ag-NPs had a potent antiviral effect against the H1N1 influenza virus and could quickly stop the virus from agglutination of erythrocytes in chickens. Additionally, Ag NPs might lessen the apoptosis that the H1N1 influenza A virus caused in MDCK cells. Along with explaining how Ag NPs reduce H1N1 influenza A virus infectivity, the scientists also proposed the use of Ag NPs as an effective antiviral treatment for influenza.

The majority of papers have speculated that Ag-NPs may attach to the exterior proteins of viral particles, inhibiting binding and preventing the multiplication of viral particles in cultured cells. This is an overview of the antiviral effects of Ag-NPs. Ag-NPs are still recommended as possible antiviral medicines in the future, even if their antiviral mechanism is not fully understood yet [54].

3.1.2.Antibacterial activity

Antibiotic-resistant bacteria are a serious health concern that has a significant worldwide impact. Pharma businesses have concentrated their efforts in recent years on creating new antibiotics that are more able to combat bacterial illnesses [55]. A huge surface area and significant synergy resulting from multivalent interactions of NPs have made them particularly effective against bacterial infections. Because of their broad antimicrobial efficacy against several bacteria, AgNPs are the most widely utilized antibacterial nano agent [56]. Although AgNPs interact with one another via the bacterial cell membrane, the major cellular target is yet unclear. AgNPs and antibiotics work together to boost antibacterial action against microorganisms that are drug resistant [57]. Multidrug-resistant bacterial growth in S. Typhimurium was suppressed when AgNPs and known antibiotics such as tetracycline, kanamycin, neomycin, and enoxacin were used together [58]. However, this synergistic effect is not shown with penicillin and ampicillin. The antibacterial activity of Ag NPs increases against *S. aureus* and *E. coli* when combined with other popular antibiotics as vancomycin, tetracycline, streptomycin, amoxicillin, ciprofloxacin, gentamicin, and erythromycin [59], while chloramphenicol, ampicillin, and kanamycin showed synergistic belongings against dissimilar bacterial strains such as St. mutans, St. aureus, Ent. Gram-positive bacteria are more resistant to the antibacterial effects of nanomaterials than Gram-negative bacteria. AgNPs have the ability to continuously release Ag^0, which is thought to be a method of killing bacteria. Ag^0's electrostatic affinities for sulfur proteins cause silver ions to cling to the cytoplasmic membrane and cell wall. Increasing the cytoplasmic membrane's permeability causes the bacterial envelope to be disrupted [59]. The uptake of Ag^0 into the cells results in the inactivation of respiratory enzymes, the production of ROS, and the cessation of ATP generation [60]. DNA modification and cell membrane rupture are two mechanisms in which ROS can be quite important. DNA is altered as a result of Ag^0's interaction with its sulfur and phosphorus constituents. Ag^0 can denaturize ribosomes in the cytoplasm, which can also stop the synthesis of proteins [61].

Without releasing silver ions, silver NPs can potentially kill

germs on their own. Ag NPs bind to the cell surface and accumulate in the pits of the cell wall, disrupting the cell membrane [62]. Similar to how they affect bacterial signal transduction, Ag NPs can stop bacterial cell division and induce death by dephosphorylating tyrosine residues on peptide substrates [63]. The ability of Ag NPs to dissolve in the exposure medium has an impact on how effectively they are antibacterial. The inherent features of Ag NPs (such as form, size, and capping agent), as well as the surrounding medium (organic and inorganic components), have a direct impact on the dissolving effectiveness of AgNPs [64-66].

Gram-negative bacteria are more vulnerable to AgNPs because of the strong cellular walls of Gram-positive bacteria, which may prevent AgNPs from entering their cells [67]. By preventing their movement, biofilm development in the oral environment shields bacteria from Ag^0 and AgNPs. The diffusion coefficients of the AgNPs control their mobility and bioavailability in the biofilm [68, 69]. In their study of AgNPs' biocidal effects on E. coli, Ivan Sondi and B.S. Sondi (2004) confirmed the "pit" development in the cell wall of this representative Gram-negative bacteria. The buildup of AgNPs in the bacterial membrane caused a considerable increase in permeability, which led to cell death [70].

3.1.3. Antifungal activity

Fungal infections have played a significant role in the rising morbidity and mortality from the prehistoric era. According to research, harmful fungal outbreaks can be managed by taking use of NPs' fungicidal or fungistatic properties [71]. *Trichophyton mentagrophytes*, *Aspergilus niger*, *Fusarium semitectum*, *Issatchenkia orientalis*, *Candida glabrata*, *Phoma glomerata*, *Phoma herbarum*, and *Candida albicans* are just an insufficient of the phytopathogens that are hostile to biosynthesized AgNPs stabilized with sodium dodecyl sulfate [72].

AgNPs stabilized with surfactants of size 25 nm have been shown to have important antifungal action by Panacek et al. These AgNPs are toxic to four Candida strains, with MIC values ranging from 0.21 to 1.69 mg/L [73]. The antifungal activity of maize extract-biosynthesized AgNPs hostile to the phytopathogenic fungus Phomopsis vexans was demonstrated by decreasing the development of mycelium by 30–40% in Potato Dextrose Agar (PDA) medium [74]. Elgorban et al. investigated the antifungal activity of AgNPs against Rhizoctonia solani, a plant pathogenic fungus that infected cotton plants [75]. Similar to this, it has been documented that two plant pathogenic fungus (*Bipolaris sorokiniana* and *Magnaporthe grisea*) are resistant to the antifungal action of Ag ions and AgNPs [76].

The mechanistic processes listed below are thought to be in charge of AgNPs' antifungal activity: Due to (i) the ease with which fungal cells may absorb AgNPs due to their tiny size, which results in the disruption of fungal cell walls, and (ii) the function of AgNPs as a source of Ag^+ ions that prevent DNA replication and ATP production through the formation of hydroxyl radicals and ROS. As a result, the fungal cells' metabolic cycle is interrupted, leading to fungal cell death. Ag^+ ions demonstrate anticandidal action by inhibiting ATP generation and enzyme function, which causes cell death due to their significant affinity for the thiol groups of the cysteine protein in fungal cells [77].

3.2.Catalytic Activity

In general, the existence of an efficient catalytic medium requires a high surface area and substantial surface energy, which are visible from metal NPs. Ag NPs in the development stage were found to be more effective catalysts than stable colloidal NPs. Due to their unique possessions, which can be incorporated into a wide range of requests, including antiseptic agents in the medicinal industry, catalysis, cosmetics, bioengineering, food packaging, environmental uses, and electrochemistry, Ag NPs are of specific interest in the current research on nanotechnology. In addition, these noble particles showed many more catalytic activities likened to their bulk materials. Numerous novel techniques have emerged as a result of the widespread interest in nanocatalysis. For instance, metal ions, silver, gold, and platinum, are well-known catalysts in the conversion of H_2O_2 to oxygen [78]. In the emission system of chemiluminescence from luminol-H_2O_2, Guo et al. [79] describe the catalytic potential of Ag NPs in comparison to the gold and platinum NPs.

In this comparison, Ag NPs outperformed gold and platinum NPs in terms of catalytic response. Moreover, the use of Ag NPs immobilized on silica spheres can improve the catalysis of the reduction of dyes by sodium borohydride ($NaBH_4$). The pace of the reaction was nearly motionless in the absence of silver nanoparticle catalysts, and it was demonstrated that there was little to no reduction of the dyes.

Figure. 2 Applications of silver NPs[80].

3.4. Gene therapy, biosensors, and diagnostics

Because they may be created with specific features or in a specific manner, NPs offer an edge over the medicines used now. They support cellular imaging. Silver's greater and sharper Plasmon resonance makes it a key component in imaging systems. Currently, silver-based biosensors are an effective technique for detecting the cytochrome P53 marker for head and neck squamous cell carcinoma. Ag NPs may be used to detect levels of sulfide as well as the heavy metal ions nickel, mercury, and cobalt, thanks to their colorimetric sensing ability. All varieties of silver NPs, but particularly those with a triangular shape, have increased anisotropy and the lightning rod effect, which makes them popular for use in the production of Plasmon sensors or Plasmon probes or Plasmon detectors, which are used to find mercury ions in solutions.

Biosensors are extensively used in the fields of food, health care, medicine, environment, etc., to detect pollutants or chemicals in various samples. Additionally, research has shown that the usage of nanomaterials in biosensors has shown significant improvement. AgNPs have been used successfully by Ngeontae et al. [81] as a potentiometric redox marker for the detection of glucose in foods and drinks. Additionally, although with much better sensitivity, Mehrgardi and Ahangar suggested the use of AgNPs as a reporter in bio-sensing the mismatch of a single base pair in DNA hybridization. AgNPs are now often utilized in kits for the highly sensitive identification of harmful microorganisms present in human samples[82].

For instance, Legionella pneumophila, which is responsible for Pontiac fever and Legionnaires' illness, is detected using inexpensive silver NPs in graphene quantum dots. Even at 1 ZM (Zepto-molar), it can identify the DNA levels of harmful bacteria. For the on-site detection of mercury ions at the ppb level, a biosensing technique based on Ag NPs, silk, and fibroin has been used. Conclusion: Biosensors based on silver NPs have an extensive range of applications and are very sensitive, quick, portable, and inexpensive.

The electrochemical sensor used to detect the ubiquitous herbicide atrazine was also developed using silver NPs. On the other hand, the speedy collection and detection of malachite's green residue are owing to the in situ growth and development of Ag NPs on polydopamine-traced filter paper [83].

3.5. Controlling cancer using Ag NPs

Ag NPs have a strong anticancer potential because it inhibits the mitochondrial respiratory chain, boost the production of reactive oxygen species (ROS), and ultimately cause DNA damage and cancer cell death. The therapy with camptothecin and Ag NPs greatly raises the number of cancer cells, according to research by Yu-Guo Yuan published in 2018. In comparison to a single treatment, it increases oxidative stress indicators and decreases anti-oxidative stress markers. These findings collectively showed that camptothecin and Ag NPs cause cell death by altering the permeability of the mitochondrial membrane and activating caspase. Increased ROS production and antioxidant depletion appear to be related to the synergistic cytotoxicity and apoptotic impact. Certainly, a combination of CPT and Ag NPs is more effective than immunotherapy in the treatment of cervical cancer[84].

Although considerable side effects and systemic toxicity have been observed, there are already a number of anticancer medications available on the market for treatment alternatives and to manage cancer mortality [85]. Finding novel therapeutic anticancer materials to treat malignant tumors is an exciting area of research in the realm of nanomedicine [86, 87]. Because they are less invasive, cancer treatments mediated by nanobiotechnology have excellent specificities [88, 89]. Fascinatingly, metallic NPs represent an intriguing platform for future cancer diagnostics and therapy due to their special features for high penetration and target specificity, respectively [90]. Ag NPs made employing microorganisms were schematically shown as having anticancer action. Metallic NPs may also be connected to biological elements like peptides, monoclonal antibodies, DNA/RNA, and/or tumor markers in order to specifically target cell surface proteins or receptors on cancer cells [91]. As a result, AgNPs have thus far shown promise as an anticancer agent in vivo settings.

4. Future prospects

As a possible treatment for infectious disorders and a growing number of infections caused by resistant bacteria, Ag NPs are also gaining recognition for their anti-inflammatory properties. In addition, it has several uses in the biological and scientific domains, including electrochemistry, biochemistry, nanoprism synthesis, the clothing, detergent, and soap industries, as well as the development of surgical instruments and water purification systems. AgNPs have now ushered in a new age by being utilized in artificial implants that mandate antibiotic dependence. Studies have shown that Ag NPs offer the innovative potential for the creation of new pharmacological dosage forms and that Ag NPs are extremely useful in treating bladder inflammation. Ag NPs are excellent for detecting biosensors in animal models [92]. Future research will concentrate mostly on this mechanism since it is believed to be responsible for the exceptional biological activity of Ag NPs. There is a lot of room for improvement in terms of stabilizing the Ag NPs used in mechanical and medical devices as well as reducing the discharge of silver.

5. Conclusions

The main advantage of employing green techniques to make NPs over microbes, algae, and plants is that the procedure does not need cultivating germs or installing the essential protections to prevent losing the ability to make NPs, which is a time-consuming process. These affordable, straightforward, and ecologically friendly Ag NPs stress greener procedures. Therefore, there is a drive to establish more environmentally friendly processes as green chemistry gains popularity and is employed to produce Ag NPs.

Despite the fact that many biological substrates are used to create silver NPs, yeasts, algae, and plants are frequently used for the direct, robust synthesis of Ag NPs due to their ready availability, variety of available options, non-hazardous nature, and advantage of faster synthesis than other techniques. In essence, the green synthesis of metal NPs using plant extracts has a range of applications, including pharmaceutical, therapeutic, renewable energy, environmental, as well as other commercial products; It has an estimated impact on the diagnosis and treatment of many diseases with specific side effects. In addition, Ag NPs possess a variety of bioactivities that make them effective weapons against cancerous tumors as well as deadly diseases. Additionally, the detection and tracking of cancer treatments involve silver NPs. Numerous in-vitro and a few in vivo anticancer investigations are currently being conducted. This opens up a number of new research opportunities for using Ag NPs to cure cancer. Current applications of Ag NPs include molecular imaging and diagnostics, drug administration, cancer therapy, treatment of vascular disorders, and wound healing. In addition, it has expanded to include state-of-the-art medical tools such catheters with antimicrobial properties. Similarly, by learning how to harness these Ag NPs as energy-driven devices, we may find a viable remedy for the current energy issue.

Conflict of Interest

The authors affirm that they have no financial or other conflicts of interest.

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