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(Review Article)

Green synthesis of silver nanoparticles from various plant extracts and its applications: A mini review

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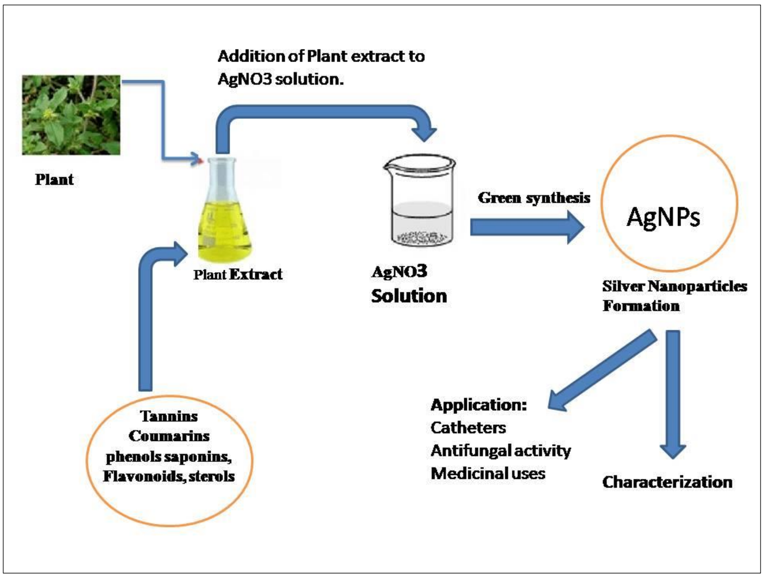
Abstract

Developing environmentally acceptable and reliable nanoparticle production technologies is a crucial step in nanotechnology. Because of their unique chemical, physical and biological properties, AgNPs have the potential to be used in various ways. As potential agents, biomolecules got from a variety of plant components were used to make it. Despite many academic efforts in the previous decade, synthesizing stability with greater applicability remains a serious challenge. This review reviewed the most recent advancements and breakthroughs in the manufacture of biogenic AgNPs, as well as their potential uses.

Graphical abstract



Keywords: Silver nanoparticles; Biosynthesis; Nanotechnology; Plant extracts

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1. Introduction

Nanotechnology is the domain of material science study that is advancing the fastest. Biosynthesis of nanoparticles is becoming a hot topic all across the world. It has emerged into an interdisciplinary approach that deals with nanostructured materials (1 - 100 nm). The physiochemical attributes of materials differ considerably than those of equivalent materials in bulk [1].

From ancient methodologies to chemical, medical, and environmental sciences, this field encompasses a wide spectrum of applications. It is playing a critical role with its vast application in nano-medicines, chemical sensing, drug delivery, data storage, cell biology, textiles, food industries, antioxidants, photocatalytic organic dye-degradation, cosmetics, agriculture and antimicrobial agents [2].

It broadly categorized into organic, which incorporates mainly carbon and inorganic, which incorporates semi-conductor, metallic and magnetic. The production of nanoparticles via conventional methods is toxic to environmental and expensive. With the rising concern for the environment and need for an eco-friendly approach, researches are on a verge of synthesizing nanoparticles using green routes. Bottom-up and top-down techniques to NP synthesis are both viable options [3]. The latter is unpredictable, but while the former causes the self-assembly of atomic-sized particles to produce nano-sized particles that can be transferred via chemical and physical methods.. Green synthesis is cost-effective, proliferate, and cause stable NP creation [4].

Nanoparticles of Gold and Silver furnish superior characteristics and useful flexibility. Silver nanoparticles receive significant interest because of their substantial surface zone with significant potential application in biochemical reactivity and catalytic activity [5]. Biocompatibility has been one of the main reasons for the growing popularity of green technologies. Stabilizer/ capping agent (size controller and agglomeration preventer) synthesis membranes, viral DNA, diatoms, plant extracts, yeast, bacteria, and actinomycetes are widely used [6]. Synthesizes off. AgNPs have been produced from a variety of sources, including microbes and plants, allowing with minimal contamination for industrial production [7].

Plants have been extensively exploited, in contrast to microbes, because their phytochemicalshowbetter decrease and stability [8]. It seems to be helpful over electrochemical reduction and heat evaporation.

The essential prerequisite for the production of AgNPs is Ag^+ ions, which can be made from a variety of silver water-soluble salts; most studies have employed an aqueous $AgNO_3$ solution with Ag^+ ions in concentrations ranging from 0.1 to 10 mm (most often 1 mm).Due to their broad array of applications, such as cancer diagnosis and treatment, significant interest in synthesis or production of AgNPshas always beeninthe scientific community [9]. The AgNPs have piqued researchers' curiosity in the past because of their organic and physio-chemical properties.. It has high thermal conductivity, chemical stability, catalytic and nonlinear optical behavior which allows having the ability to value in inks, microelectronics, and clinical imaging [10].

Plant extract which receives plenty of attention for the simplicity, rapid synthesis with removal of detailed maintenance in cell cultures with eco-friendliness mediates the most sophisticated method for synthesizing nano-particle. AgNPs biosynthesis is carried out through plants as they have necessary reducing agents like flavonoids, citric acid, ascorbic acids, reductases, saponins. Dehydrogenases and extracellular electron shuttersare also involved in metallic AgNPs biosynthesis. Present review draws an attention regarding AgNPs biosynthesis using different plant extract material which enables the researchers as a potential source of green synthesis of nanoparticle.

2. Synthesis of silver nanoparticles

2.1. Physical synthesis

Top-down process refers to microfabrication where gears are used to cut, mill and shape substances into a particular shape (Fig. 1). Lithography and laser ablation reduce the scale of silver metal robotically to the nano-scale [11]. The formation of nano-structured materials has fewer defects and many equivalent chemicals with a brief and long variety of ordering [12]. In the top to backside process, evaporation–condensation primarily synthesized NPs in the furnace.

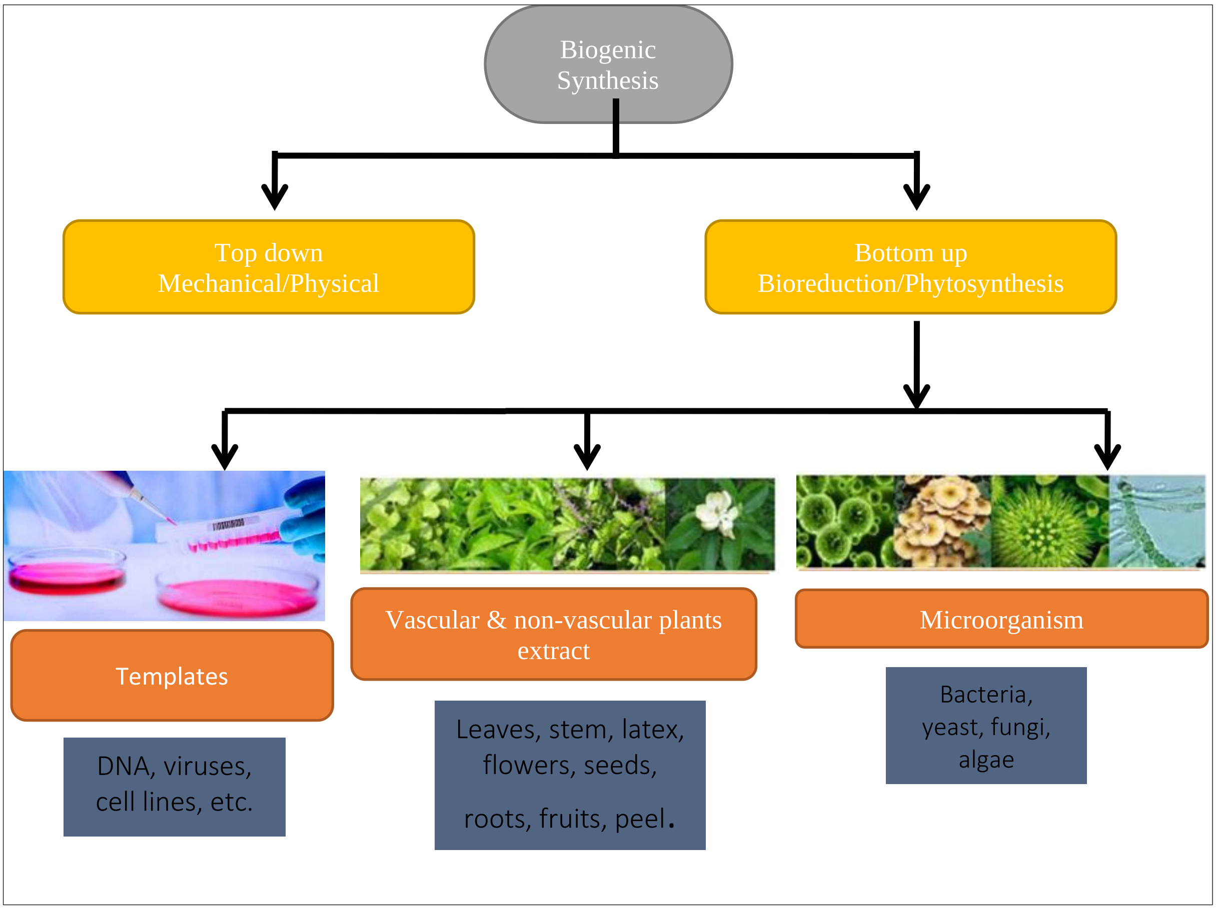

Figure 1 Biogenic synthesis of nanoparticles

In this approach, they confined the base materials inside a boat and vaporized into carrier gas in the furnace's center point. Ag, Au, $PbSO_4$, CdS and fullerene nanoparticles formerly produced by use of the evaporation or condensation approach. Several demerits are seen when synthesis of AgNPsare done using a tube furnace [13]. To achieve a consistent working temperature, a conventional tube furnace consumes hundreds of kilowatts of energy and requires tens of minutes of preheating time. Silver nanoparticles were indeed produced with less solution ablation of metal bulk materials [14]. As a result, laser ablation has an advantage over other conventional methods of generating metallic colloids in the absence of chemical reactions in solutions.So natural colloids, with the intention to be beneficial for similar packages, can be produced via this method [15].

2.2. Biological synthesis

The silver nanoparticles synthesis by physical and chemical methods are highly expensive. Nano particles from chemical synthesis are not medically suitable as they have absorbed toxic substances absorbed onto their surfaces. In order to get commercialized,it must cost the nanoparticles effective. In order to get an economically workable method and environmentally sound, researchers have pursuit such alternative synthesis method by investigating on biological substances. They discovered nanoparticles made from microorganisms and plant extracts are more cost-effective and act as reducing and stabilizing agents. Microbial enzymes and plants with oxidation or reduction characteristics are used to make nanoparticles in green biotechnology [16] (Fig. 2).

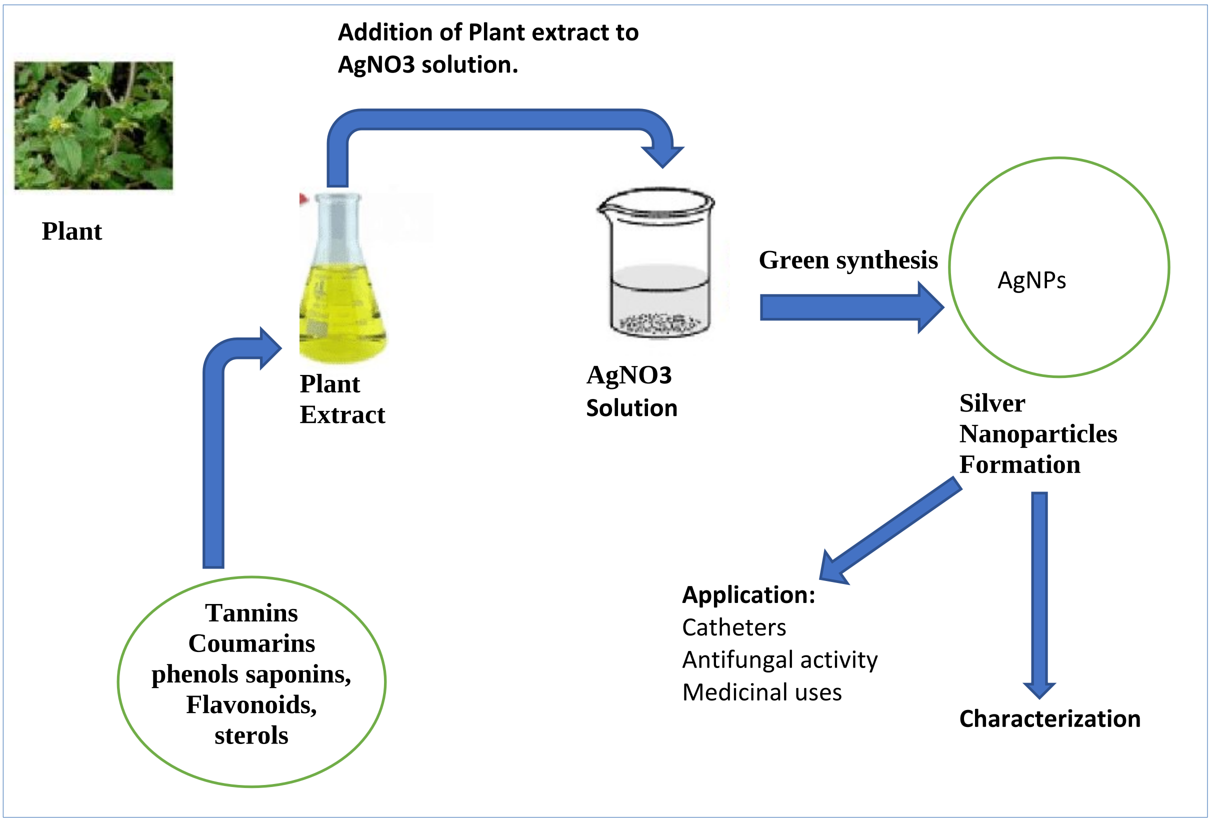

Figure 2 Schematic diagram of green synthesis of silver nanoparticles

2.3. AgNP Synthesis in Plants

To synthesize AgNPs, plant extracts were being used and because of their availability, low toxicity, and safety, they may be preferable to bacterial and fungal synthesis [16]. AgNPs' properties are determined by the plant extract sources. Individual phytochemical and phytochemical combinations in extracts differ substantially depending on the plant source [17]. As a result, changing the extract composition can change the characteristics of AgNPs [18]. For biosynthesis, an aqueous AgNO3 solution is mixed with an aqueous plant extract at an ambient temperature only for a few minutes [19]. Large amounts of phytochemical capable of producing AgNPs have been identified [20]. Plants with functional groups, including hydroxyl, aldehyde, ketone, carboxyl, and aino can decrease Ag+ ions [21]. The specific method of AgNPs synthesis differs depending to phytochemical variety. Specific functional groups reduce the Ag+ ion, which is one of the key processes. The hydroxyl groups in all the compounds allow Ag+ ions to be reduced, resulting in AgNPs production [22]. Phytochemical are not all the same, which is surprising. Only a few phytochemical discovered from plant extracts reduce Ag+ ions. A wide range of plants include phytochemical, which serve as an organic reducing agents. And according to the study flavonoids are only responsible for AgNPs synthesis. (Fig. 3).

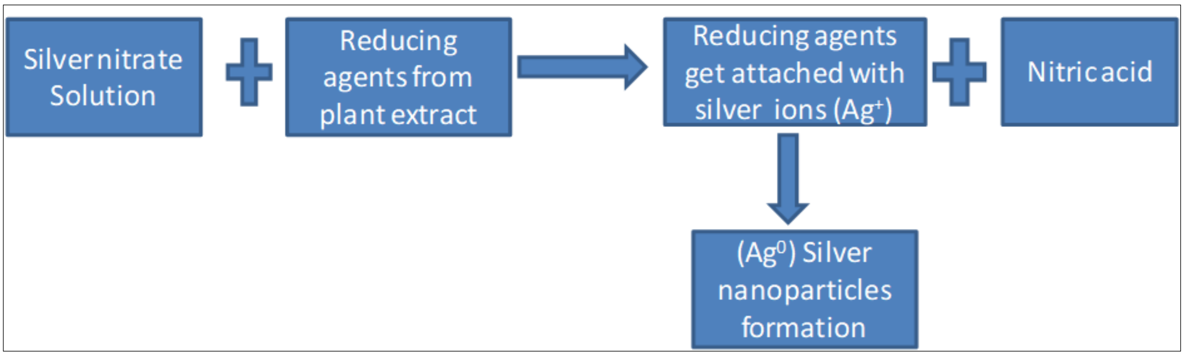

Figure 3 Synthesis of AgNPs by reaction of $AgNO_3$ with phytochemicals

2.4. Synthesis of silver nanoparticles from various plant extracts

2.4.1. Aloe vera nanoparticles

Recent study on aloe vera plant has given rise to In_2O_3 (Indium Oxide) nanoparticles with ~~of~~ particles size ranging from 5 to 50 nm. This is cost effective and eco-friendly. Calcinations get these nanoparticles, the dried In_2O_3 precursor in a hot air oven at 400-600°C for 2 hours. As it is characterized by XRD (X-ray diffraction) (Pw 3040) with CuKα radiation (λ= 0.15406nm) and TEM analysis [23]. Aloe Vera plant extracted solution synthesized an extremely adopting cost effective precursor for preparation of In_2O_3 nanoparticles. It successfully synthesized AuNPsin a single crystalline triangular form (~ 50 - 350 nm) and AgNPs in spherical form (~15nm) to be used for other biomedical approaches.

Half of the AgNPs generated with aloe-vera extract had mosquitocidal and antibacterial properties [24], which is a benefit. At low doses, the $LC_{50}$of aloe-vera AgNPs evaluated against *An. stephensilarvae* and pupae was 3.825 ppm. After 24 hours, 48 hours, and 72 hours, aloe-vera synthesised AgNPs (10 × LC_{50}) reduce *An. stephensi* larvae reduction to 74.5, 86.6, and 97.7%, respectively, under outdoor circumstances. Aloevera leaf extract synthesised silver nanoparticles showed greater fungicidal activity against *Rhizopus* sp. and *Aspergillus* sp. [25] on the application of 100 µL of 1 M silver nanoparticles.

2.4.2. Citrus limon (lemon) nanoparticles

Citrate and ascorbic acid act as reducing agents to make AgNPs and AuNPs [26]. As lemon content is bothtypes of acids, it is reliable to producea green synthesis of nanoparticles. It took varieties of concentration of silver nitrate solution (10−2 M, 10−3 M and 10−4 M) which are interacted with lemon juice with a different ratio for a different time in 30°C within a rotary shaker of 120 rpm. After centrifugation of 10000 rpm for 10 minutes, separate the pellet and then freeze-dried using lyophilizer to harvest. UV visible spectroscopy, X-ray diffraction, Fourier transform infrared spectroscopy, Atomic force microscopy, and Transmission electron microscopy (TEM) were used to characterise this. These AgNPs are spherical and spheroidal (< 50 nm).

On cotton and silk materials, the extracted silver nanoparticles provided a long-lasting textile finish [27]. Because of the synergistic action of Ag^+ and lemon leaves, essential oil components convert Ag+ ion to Ag0. AgNPs generated has high antimicrobial activity. It inhibits *Fusarium oxysporum* and *Alternaria brassicicola* growth on agar diffusion medium. FT–IR was used to studying the formation [28]. Lemon extraction was made and combined with the solution, which was monitored using a spectrophotometer, FESEM, and EDAX analysis. Dermatophytosis patients' skin scales were treated with this lemon-derived AgNPs were found to have anti-dermatophyte action and also cost-effective.

2.4.3. Menthaasiatica (Mint) nanoparticles

Menthaasiatica has a good inhibitory activity in a bactericidal action against *Escherichia coli* and *Pseudomonas aeruginosa*, with gram-negative bacteria. It started the process with extract suspension of mint leaf treated with $AgNO_3$~~,~~ 20 minute it changes colour to white and after proper incubation of 5 hr gives outcome of silver nanoparticles [29]. This is characterized by spectral analysis showing SPR in 200 to 600 nm. These AgNPs have the ability of antimicrobial, antimalarial, antidiabetic, antioxidant and anticancer pastime.

AgNPs from mint extract (5 -50 nm) is achieved by various physio-chemical and organic techniques.Bio-reduction is achieved using AuNPs with a spherical and triangular shape (3–26 nm). *Menthapiperita* leaf extract act as a reducing agent forsynthesis of AuNPs. The content of leaf extract regulated it, as well as the time and temperature factors. With a leaf extract concentration of 1.5% (leaf extract) at 70°C for 3 minutes, the best bio reduction was achieved [30].

Produce AgNPs are toxic and hazardous for microorganism which helps inthe drug delivery system in medicine. NPs from the Mentha species extract are active against six bacteria: *Bacillus fastidiosus* (the highest inhibitory effect), *Proteus mirabilis, P. vulgaris, Salmonella choleraesuis, Escherichia coli, Pseudomonas aeruginosa, Klebsiella pneumoniae and Serratiaodorifera* except for *Staphylococcus aureus*.

2.4.4. Ginger nanoparticles

Ginger extract Copper nanoparticles are mostly multifunctional inorganic nanoparticles have a capacity of heavy antibacterial activity in gram-positive bacteria [31] green synthesised CuNPs with sizes of 40 and 25 nm, respectively. *Ginger* root is rhizome of a plant *Zingiber officinale* which is mostly used for copper nanoparticle formations. The plant was crossed and dispense in 10 ml of sterile distributor undated for 23 minutes at 70°C extract filtered using whattman filter paper, then sterilize method is applied on it. Then 1:1 of $CuSo_4$ solution to get nanoparticles.For silver nanoparticles production the Ag+ and $AuCl_4^-$ions.5 ml of ginger rhizome broth at room temperature was added to$AgNO_3$and $HAuCl_4$ solution (1.0×10-3 M) of 50 ml separately, incubated in dark in a shaker at 120 rpm at 37°C. A UV-visible spectrophotometer can conveniently monitor the bio-reduction of aqueous Ag+ and $AuCl_4^-$ ions [32]. Produced Gold nanoparticle are of 5-20 nm whereas silver nanoparticle are 35-46 nm.Biosynthesis of multiple shaped AuNPsfrom *Colletotrichumsp,*which grows on geranium leaves, was studied [33].

The ginger-derived nanoparticle (GDN) was employed to activate nuclear factor erythroid 2-related component 2 (Nrf2), which triggered the expression of a set of liver detoxifying/antioxidant genes while suppressing reactive oxygen species generation [34]. Ginger protects the liver from the hepatotoxic effects of carbon tetrachloride, ethanol, and acetaminophen. As a result, the nanoparticle made from ginger could be used as a new liver-protective agent.

2.4.5. Hibiscus rosa nanoparticles

Zinc Oxide nanoparticles are synthesis by the bio components of leaves extract of *Hibiscus rosa* sinensis. These nano particles are multifunctional, inorganic and crystalline, simple and eco-friendly methods synthesized this. Zinc oxide nanoparticles biosynthesis was carried out from *Hibiscus rosa* leaf extract of has used for a reducing material as well as stabilizing material for [35]. 5 g of fine washed dried leaves powder with 100 ml double distilled water, which were utilised for the reduction of Zn^{2+}, zinc nanoparticles (ZnO). After boiling for 60-80 minutes, add 5 g zinc nitrate and watch the colour change. They then roasted the pest in a furnace for two hours at 400 degrees Celsius, resulting in a light yellow powder. Between 30 and 35 nanometers are the size of the ZnO crystallites.

The nps are characterized by TEM, XRD and FTIR spectroscopy [36]. pH fluctuation of medium affectsdistinct shape of AgNPs. FTIR analysis has shown that the AuNPs are bound to amine groups and the AgNPs to carboxylate ion groups. The SEM analysis reveal the particle to be spherical and size ranges from 5 to 40 [37]. AgNPshave essential applications in medicine on antimicrobial agent. They have effective bactericidal against *Catlacatla* fish infected with *Aeromonashydrophila.*

2.5. Characterization of Silver nanoparticles

Researchers typically use centrifugation to gain pellet or powder form of generated AgNPs which are oven dried. They did AgNPs characterisation using UV-Vis Spectra, SEM, TEM, FTIR, XRD, and EDAX [38]. DLS instead of plant and microbes is commonly utilised for AgNPs made from biopolymers. Zeta potential is determined for AgNPs stability. AgNPs stability and organic composition due to $AgNO_3$ and L-cystine influence was determined using TGA [39]. ICP analysis was carried out to investigate AgNPs concentration and conversion [40]. The synthesised AgNPs' SPR peak was observed in the 400-450 nm region, which is the important range for AgNPs [41]. The size-stability of manufactured AgNPs has been revealed using UV-Vis spectral studies, a shift in a red peak in the SPR peak shows an increase in size and blue peak reveals vice versa. The creation of face-centred cubic (FCC) crystalline structured AgNPs with Ag weight ranging from 45% - 80%demonstrate demonstrated by almost all the studies using XRD measurements. Cubic and hexagonal forms have been reported in several cases.

A 45% - 80% Ag weight EDS or EDAX optical absorbency band determines nanomaterials elemental composition to be around 3 KeV. Of the all circumstances observed the stability of synthesised nanoparticles to range from 1 day to 1 year.

2.6. Various applications of silver nanoparticles

The silver nanoparticle has many applications in medical, industrial, pharmacological (like anti-microbial activity, antibacterial property, anti-fungal activity etc. and environmental. It plays a major role in disinfecting of medical devices and water treatment [42]. Currently, nano materials are used in the prevention, diagnosis and treatment of most cancers the usage of photo-based therapeutic applications [43] with little irradiation energy density nanostructures are effective in destroying the most cancers cells than non-most cancers cells [44].

3. Pharmacological application

3.1. Anti-bacterial activity

It may significantly assimilate AgNPs into biosensor materials, antimicrobial applications, wound healing, cosmetics, textile industry, etc. They are significant in the sector of medicine and biology because of their antimicrobial actions on pathogens [45]. Antimicrobial agent silver has been known for centuries; the latest resurgence interest for this element especially makes a speciality of the increasing risk of antibiotic resistance, due to the wrong use of antibiotics [46] Development of antibiotic resistance amongst bacteria, it is necessary to make that alternative antibacterial therapy. The AgNPs release classical bactericidal towards both Gram-positive and negative [47]. The antimicrobial pastime might be because of either (i) pore formation in mobile wall ending in a long run as leakage of cellular content material or (ii) the Ag^{+} perforate thru ion channels does no harm to the membranes; instead denatures the ribosome, hold back the enzymatic expression and thiol proteins necessary in manufacturing ATP and DNA leading to elimination [48].

3.2. Anti-fungal activity

AgNPs are sophisticate and effective fungicides towards an extensiverange of fungal sp. which includes Aspergillus, Candida and Saccharomyces [49]. AgNPs of *Withania sominifera* have shown antifungal against fungal pathogens like *A. niger, A. flavus* and *C. albicans* [50]. Recently, research found antifungal from AgNPs from Tulsi (*Ocimum sanctum L.*) against opportunistic human fungal pathogen [51]. It took AgNPs into consideration as aneffective fungicidalagainstfungi, inclusive of *Aspergillus, Candida* and *Saccharomyces.*

3.3. Medical devices and water treatment

AgNPsare used predominantly in ointments not only used to prevent but with healing activity towards wounds, burns and infections [52,53]. They may recruit for water purification and filtering apparatus due to its superior antimicrobial nature [42]. Silver nanoparticle is used for purification of water by stopping the growth of pathogenic microbes through editing or coating the floor. It is accepted with much consideration for biomedical gadgets and in FMCG industries. The coatinghas to possess effectiveness, easy fabrication of lower toxicity [54]

3.4. Catalytic activity

The reduction of the methylene blue was significantly achieved by filtered aqueous extract of *Terminalia chebula* fruit powder [55] besides draw out of *Acacia nilotica* pod mediated AgNPs altered glassy carbon electrode confirmed extra catalytic interest on the discount of benzyl chloride which is compared to [56] the ones of glassy carbon and metallic.

3.5. Anticancer *in Vitro*

Techniques for preparing anti-cancer AgNPs are now being studied in depth.. AgNPs made from biological sources showed considerable inhibitory action against the survival of various malignant cell lines. The reducing agents in those approaches were plants components extracts (e.g., leaf, root, flower, or fruit). The HNGC2 cell line, which is brain cancer, was reported to be inhibited by biosynthesized AgNPs [57]. These spherical AgNPs have IC_{50} values ranging from 20 to 80 nm in a dose-dependent manner [58]. The cervical cancer cell lines Siha and HeLa were found to be inhibited by biosynthesized AgNPs. 2–18 nm triangular and hexagonal AgNPs with an IC50 of 4.25 g/mL reduced the Siha cancer cell line's proliferation [59]. AgNPs inhibited HeLa cancer cell lines with diameters ranging from 5 to 120 nanometers. The AgNPs manufacturing technique and plant extracts employed influenced the IC_{50} values. Hexagonal AgNPs with an IC_{50} of 4.25 g/mL. The biosynthesised AgNPs inhibited four colon cancer cell lines with IC_{50} values ranging from 5.5 to 100 g/mL [60]. With diameters ranging from 7.39 to 80 nm, the particles were essentially spherical. Cuboidal and spherical bio-AgNPs (59 -94 nm) have IC_{50} values between 78.58 - 83.57 g/mL, inhibiting A431 and epidermoid cancer cell line [61]. Spherical AgNPs inhibited a cell line of liver cancer (6.4 to 1200 nm) (Hep-G2).

Spherical bio-AgNPs (< 20 nm) inhibit the intestinal Caco-2 cancer cell line, having an IC50 value of > 30 g/ml. Spherical AgNPs (< 40 nm 95) suppressed the Hek-293 kidney cancer in a dose-dependent manner.

Size and form of AgNPs affect their cytotoxicity. The most interesting practical reason is that AgNPs of this size and shape may come into direct contact with cell surfaces, causing cytotoxicity. NPs are safe at low concentrations, but they can be dangerous at high doses. Angiogenesis is the formation of new blood vessels from existing ones, which is vital for tissue nutrition and waste removal [62]. Solid tumours are aided by new blood vessels formation [63]. This process is controlled by activator and inhibitor molecules, which act as crucial in cancer spread. Oxygen and nutrients supply to cancer cells aids the tumour growth, allowing infiltrating and metastasis [64]. As AgNPs change per inhibiting factor-induced RNV in vascular endothelial cells and block extracellular signal-related kinase.

AgNPs anti-angiogenesis properties are used to treat cancer by a various means. The cell cycle is a complicated network of signalling pathways that enables a cell to divide and replicate its DNA. This phenomenon is important in the progression of cancer. This natural system breaks down when cancer develops genetic mutations, resulting in uncontrollable proliferation. The cell arrest checkpoints are DNA synthesis, mitosis, G1 and sub G1. AgNPS has shown the cell cycle to stop in the sub-G1 phase, explaining the relationship between sub-G1 phase arrest and apoptosis in cancer cells [65]. The development of the pro-apoptotic protease caspase-3 is associated with increasing cancer cell numbers in the sub-G1 phase [66]. AgNPs have been extremely hazardous to mammalian cells in the past [67]. The risk of toxicity is present when metal is converted into its nano form. Green synthesis, on the other hand, minimises AgNP toxicity. The usual toxicity of a substance is largely determined by its covering. Green synthesis AgNPs are ideal for a variety of medical applications due to their coating [68].

3.6. Future Aspects of AgNPs by plants

Green chemistry,though non-toxic, low-cost and ecofriendly the biological approaches,has substantial limitations. AgNPs high biodegradability and clearance aid in the prevention of toxicity. AgNPs have proven as potential nanomedicine-based therapeutics. Clinical trials using AgNPs-based nanomedicine are needed to determine the application's future direction. Clinical trials must address issues like as biodegradability, dosage, and administration method. Something can also utilise agNPs to visualise and detect cancer cells in the early stages of the disease. The ability of green AgNP production to aid in vivo fluorescent tumour imaging has already been showed [69].

Abbreviations

- AgNPs; Silver Nanoparticles
- G: Grams
- UV: ultraviolet
- FESEM   Field eission scanning electron microscope
- EDAX: Energy Dispersive X-Ray Analysis
- Ag: Silver
- AuNPs: Gold Nanoparticles
- Au: Gold
- Cu: Copper
- NP: Nanoparticles
- SEM: Scanning Electron Microscope
- IC_{50}: Half maximal inhibitory concentration
- RPM: Rotation per minute
- XRD: X-ray Diffraction analysis
- SPR: Surface Plasmon resonance
- TGA: Thermo-Gravimetric Analysis
- ICP: Inductive Coupled Plasma

4. Conclusion

To develop green synthesis, many efforts have been made since last decade. Nature has developed the most capable and ingenious small helpful materials. A rising understanding of green chemistry and the utilisation of green pathways for manufacturing metal NPs, particularly Ag-NPs, provided the impetus for developing environmentally friendly methodologies. Plants that produce Ag-NPs have an advantage over other biological entities in that they can overcome the slow process of employing microbes and maintain their culture, which can lose their ability for NPs production. The advantages of synthesis from plant extracts include a sanitary working environment, health and environmental protection, less waste, and the most stable products. There is a disparity in the results that will require extra work to correct. AgNPs offer a lot of potential in cancer therapy as drug carrier, metabolites biosensors and pollutants, catalysts, cardiovascular implants, dentistry, medicine, and therapeutics, to name a few applications.

Compliance with ethical standards

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Authors’ Contributions

Arun Kumar Pradhan did the investigation and writing of the original draft manuscript. Sameer Ranjan Sahoo and Swapnashree Satapathy did the review of final manuscript, editing of the original draft manuscript and supervision. Snehalata Pradhan and Jyoti S. Prusty did the visualization, resource acquisition, and supervision. Subham Preetam did the diagram preparation. Arun Kumar Pradhan did the overall supervision. All the authors reviewed the manuscript and given consent for submission. Arun Kumar Pradhan shares the senior authorship.

Disclosure of conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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