Biosynthesis of Silver nanoparticles using plant extracts; New approach in Agriculture & Pharmaceuticals: A Review

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Abstract: *Bionanotechnology has emerged as integration between biotechnology and nanotechnology for developing biosynthetic and environment-friendly technology for synthesis of nanomaterials. Different types of nanomaterials like copper, zinc, titanium , magnesium, gold, alginate and silver have been identified but silver nanoparticles have proved to be most effective as it has good antimicrobial efficacy against bacteria, viruses and other micro-organisms. Conventionally silver nanoparticles were synthesized by chemical methods using chemicals as reducing agents which later on become accountable for various biological risks due to their general toxicity; engendering the serious concern to develop eco- friendly processes. Thus, to solve the objective; biological approaches are coming up to fill the void; for instance green synthesis using biological molecules derived from plant sources in the form of extracts exhibiting superiority over chemical and/or biological methods. These plant based biological molecules undergo highly controlled assembly for making them suitable for the metal nanoparticle synthesis. Silver nanoparticles possess unique properties which find myriad of applications such as antimicrobial, anticancer, larvicidal, catalytic and wound healing activities. Biogenic syntheses of silver nanoparticles using plants and their pharmacological and other potential applications are gaining momentum owing to its assured rewards. This paper aims to review different synthesis routes of silver nanoparticles and their applications in Agriculture & Pharmaceuticals.*

Keywords: Antimicrobial properties & *Applications, Nanotechnology, Silver nanoparticles (AgNPs) Synthesis, Plants.*

1. INTRODUCTION:

The nanotechnology process began with the generation, manipulation, and deployment of nanomaterials representing an area holding significant promise for a wide range of applications [1]. Nanotechnology has become a dynamically developing industry with multiple applications in energy, materials, computer chips, manufacturing, health care and medical diagnosis [2, 3]. Plant crude extract contains novel secondary metabolites such as phenolic acid, flavonoids, alkaloids and terpenoids in which these compounds are mainly responsible for the reduction of ionic into bulk metallic nanoparticles formation[4]. These secondary metabolites are constantly involved in the redox reaction to synthesize eco-friendly nanosized particles. Many previous reports are demonstrating that biosynthesized nanoparticle effectively control oxidative stress, genotoxicity and apoptosis related changes[5]. Additionally, nanoparticles have broad applications in agriculture industry and plant sciences. For instance, the nanoparticle using bioprocessing technology converts the agricultural and food wastes into energy and useful by-products. Based on that, the present is review focused on biosynthesized metallic nanoparticles from plant derivatives and its applications in medical and commercial sectors including waste water treatment, cosmetics and food industry.

Green synthesis of nanoparticles has attracted considerable attention in recent years. In this regard, plants extracts and natural resources such as microorganisms and enzymes have been found to be good alternative reagents in synthesis of nanoparticles . Utilizing green substances has several advantages including low energy consumption and moderate operation conditions (e. g. pressure and temperature) without using any toxic chemicals [6]. Therefore, green synthesis techniques using various biological organisms such as yeast, mold, algae and bacteria, and plant extracts have been developed for the synthesis of nanoparticles[7].

It is known that silver and its compounds are highly toxic to major species of microorganisms such as bacteria, fungus and viruses [8,9]. While the mechanisms of bactericidal and fungicidal activities of silver are not fully known, it has been suggested that silver can inhibit cell transduction and also cause cell lysis [10]. . Silver nanoparticles (AgNPs) due to their surface configuration and small size which in turn increase their surface to volume ratio exhibit amazing antimicrobial and physico-chemical properties [11]. Antimicrobial activities of silver makes it much interesting choice for application in different areas including water and air treatment, catalysis, mirrors, optics, photography, medical, dentistry, clothing, electronics, food packaging etc. [12].

A number of approaches are available for the synthesis of silver nanoparticles for example, reduction in solutions [13], chemical and photochemical reactions in reverse micelles[14], thermal decomposition of silver compounds[15], radiation assisted[16], electrochemical , sonochemical , microwave assisted process and recently via green chemistry route using various natural products like green tea *Camellia sinensis*[17], leaf broth natural rubber , starch , *Aloe vera* plant extract and recently by using lemon grass extract [18 &19].

According to data available a large number of studies on silver nanoparticles (AgNPs) have been documented on microbial and animal cells; however, only a few studies were done on plants [20] . As we know, NPs have both positive and negative effects on plant growth and development. Krishnaraj et al. studied the effect of biologically synthesized AgNPs on hydroponically grown *Bacopa monnieri* growth metabolism, and found that biosynthesized AgNPs showed a significant effect on seed germination and induced the synthesis of protein and carbohydrate and decreased the total phenol contents and catalase and peroxidase activities. Also, biologically synthesized AgNPs enhanced seed germination and seedling growth of trees *Boswellia ovaliofoliolata* [21] . AgNPs increased plants growth profile (shoot and root length, leaf area) and biochemical attributes (chlorophyll, carbohydrate and protein contents, antioxidant enzymes) of *Brassica juncea*, common bean and corn [22 & 23]. Silver nanoparticles are widely used for its unique properties in catalysis, chemical sensing, biosensing, photonics, electronic and pharmaceuticals and in biomedicine especially for antibacterial agents and antiviral agents [24]. Silver nanoparticles have a great potential for use in biological processes including antimicrobial activity [25]. Antimicrobial capability of silver nanoparticles allows them to be suitably employed in numerous household products such as textiles, food storage containers, home appliances and in medical devices. Silver nanoparticles have been widely used for development of biological and pharmaceutical processes, products, and applications such as coating material for medical devices, orthopedic or dental graft materials, topical aids for wound repair, clothing, underwear and socks, textile products, and even washing machines [26].

The antimicrobial property of silver is connected to the amount of silver and rate of silver released. Silver in its metallic state is inert but it reacts with the moisture in the skin and the fluid of the wound and gets ionized. The ionized silver is highly reactive, as it binds to tissue proteins and brings structural changes in the bacterial cell wall and nuclear membrane and nuclear membrane important to cell distortion and death [27]. Silver also binds to bacterial DNA and RNA by denaturing and inhibits bacterial replication [28]. Silver have some antifungal and antiviral activities. Silver metal and silver dressings, when used in reasonable amounts, has no negative effects on the human body towards many pathogens such as bacteria, viruses, fungi, yeast etc. [29]. The effectiveness of AgNPs could be estimated by the fact that they kill approximately 650 types of pathogenic microbes such as bacteria, fungi, viruses, yeasts etc. and kill pathogenic bacteria in a very short time, i.e., 30 min.[30].

2. GREEN SYNTHESES OF SILVER NANOPARTICLES USING PLANT EXTRACTS: [31].

The use of plants as the production assembly of silver nanoparticles has drawn attention, because of its rapid, eco-friendly, non-pathogenic, economical protocol and providing a single step technique for the biosynthetic processes. The reduction and stabilization of silver ions by combination of biomolecules such as proteins, amino acids, enzymes, polysaccharides, alkaloids, tannins, phenolics, saponins, terpinoids and vitamins which are already established in the plant extracts having medicinal values and are environmental benign, yet chemically complex structures [32]. A large number of plants have been reported to facilitate silver nanoparticles synthesis (Table 1) and are discussed briefly in the present review. The protocol for the nanoparticle synthesis involves: the collection of the plant parts of interest from the available sites and then it was washed thoroughly twice/thrice with tap water to remove both epiphytes and necrotic plant parts followed by sterile distilled water to remove associated debris if any. These, clean and fresh sources are shade-dried for 10–15 days and then powdered using domestic blender. For the plant broth preparation, around 10 g of the dried powder is boiled with 100 mL of deionized distilled water (hot percolation method). The resulting infusion is then filtered thoroughly until no insoluble material appeared in the broth. To 10^{-3} M AgNO3 solution, on addition of few ml of plant extract follow the reduction of pure Ag(I) ions to Ag(0) which can be monitored by measuring the UV–visible spectra of the solution at regular intervals[33] **Figure 1**.

Table 1 Green synthesis of silver nanoparticles by different researchers using plant extracts[31].

Plants	**Size (nm)**	**Plant's part**	**Shape**
Alternanthera dentate	50–100	Leaves	Spherical
Acorus calamus	31.83	Rhizome	Spherical
Boerhaavia diffusa	25	Whole plant	Spherical
Tea extract	20–90	Leaves	Spherical
Tribulus terrestris	16–28	Fruit	Spherical

Cocous nucifera	22	Inflorescence	Spherical
Abutilon indicum	7–17	Leaves	Spherical
Pistacia atlantica	10–50	Seeds	Spherical
Ziziphora tenuior	8–40	Leaves	Spherical
Ficus carica	13	Leaves	---------
Cymbopogon citratus	*32*	Leaves	------------
Acalypha indica	*0.5*	Leaves	------------
Premna herbacea	*10–30*	Leaves	Spherical
Calotropis procera	*19–45*	Plant	Spherical
Centella asiatica	*30–50*	Leaves	Spherical
Argyreia nervosa	*20–50*	Seeds	-----------
Psoralea corylifolia	*100–110*	Seeds	-----------
Aloe vera	*50–350*	Leaves	Spherical, triangular
Citrus sinensis	10–35	Peel	Spherical

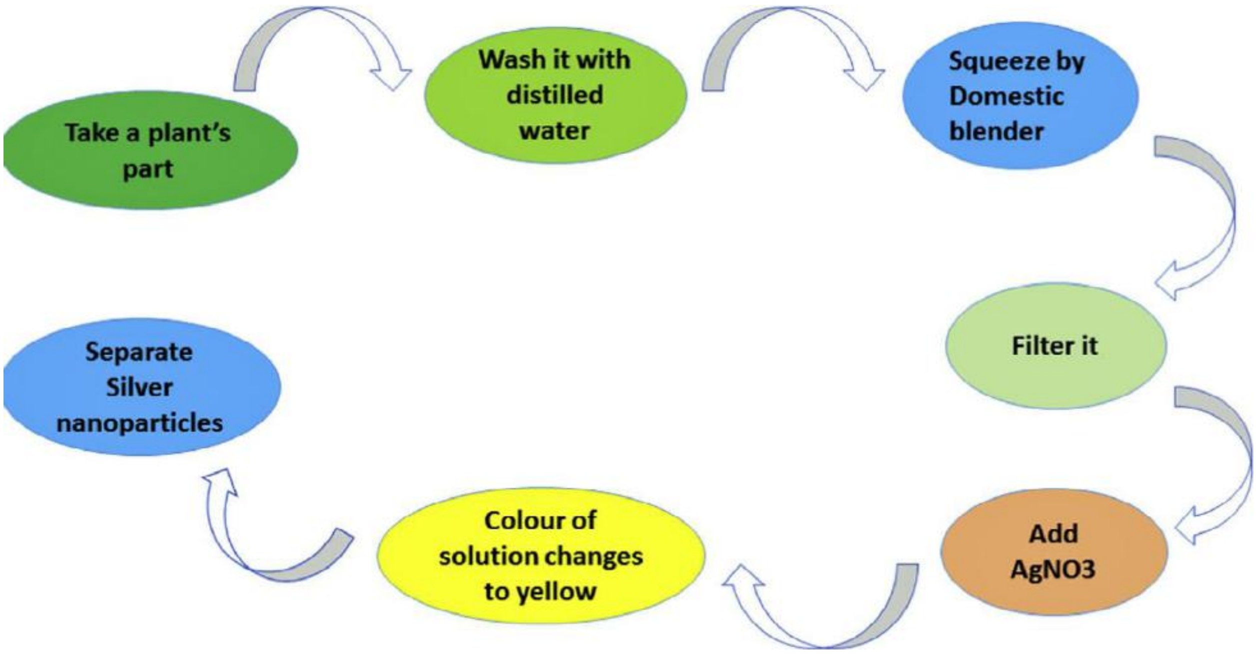

Fig. 1.Protocol for synthesis of silver nanoparticles using plant extract.

3. MECHANISM OF SILVER NANOPARTICLES SYNTHESIS:

The synthesis of Silver nanoparticles by biological entities is due to the presence of large number of organic chemical like carbohydrates, fats, proteins, enzymes & coenzymes, phenols flavanoids, terpenoids, alkaloids, gum etc capable of donating electron for the reduction of Ag+ ions to Ag0. The active ingredient responsible for reduction of Ag+ ions varies depending upon organism/extract used. For nano-transformation of AgNPs, electrons are supposed to be derived from dehydrogenation of acids (ascorbic acid) and alcohols (catechol) in hydrophytes, keto to enol conversions (cyperaquinone, dietchequinone, remirin) in mesophytes or both mechanisms in xerophytic plants [34].The microbial cellular and extracellular oxidoreductase enzymes can perform similar reduction processes. A schematic diagram showing the silver ion reduction, agglomeration and stabilization to form a particle of nanosize is shown in **Figure 2**[35].

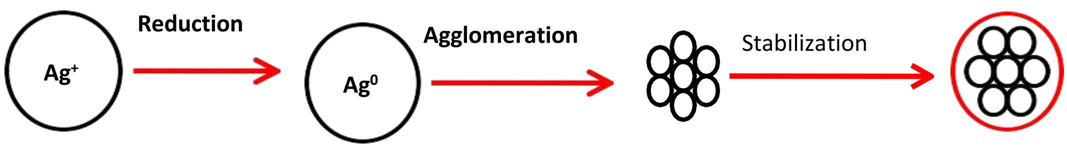

Fig.2.Synthesis mechanism of silver nanoparticles.

4. FACTORS AFFECTING SILVER NANOPARTICLES SYNTHESIS:

The major physical and chemical parameters that affect the synthesis of AgNP are reaction temperature, metal ion concentration, extract contents, pH of the reaction mixture, duration of reaction and agitation. Parameters like metal ion concentration, extract composition and reaction period largely affect the size, shape and morphology of the AgNPs [36]. Most of the authors have reported suitability of basic medium for AgNPs synthesis due to better stability of the synthesized nanoparticles in basic medium [37] [38]. Some other advantages reported under basic pH are rapid growth rate [39] [40], good yield and mono dispersity and enhanced reduction process. Small and uniform sized nanoparticles were synthesized by increasing pH of the reaction mixture [41]. The nearly spherical AgNPs were converted to spherical AgNP by altering pH, However, very high pH (pH > 11) was associated with the drawback of formation of agglomerated and unstable AgNPs [42]. The Reaction conditions like time of stirring and reaction temperature are important parameters. Temperatures up to 100˚C were used by many researchers for AgNP synthesis using bio-polymers and plant extracts, whereas the use of mesophilic microorganism restricted the reaction temperature to 40˚C. At higher temperatures the mesophilic microorganism dies due to the inactivation of their vital enzymes. The temperature increase (30˚C - 90˚C) resulted in increased rate of AgNPs synthesis [43] and also promoted the synthesis of smaller size AgNPs [44]. On the whole, most of workers have synthesized AgNPs at room temperature (25˚C to 37˚C) range.

5. APPLICATIONS OF SILVER NANOPARTICLES:

5.1. Antibacterial Action:
The AgNPs have potent antibacterial action against gram positive bacteria *Lactobacillus fermentum* , *Streptomyces* sp. *Bacillus cereus, Brevibacterium casei*, *S. Aureus, B. licheniromis*, and gram negative bacteria, *E. Coli, Entrobacteria* and *Ureibacillus thermo sphaerius*. The antibacterial action of AgNPs on gram positive and gram negative bacterial strains is not the same but competes one over the other. The antimicrobial action of AgNPs can be categorized in two types: the inhibitory action and bactericidal action. The mechanism behind the bactericidal action of AgNP was illustrated by release of Ag+ ions, which serves as reservoirs for anti-microbial action. The Ag+ cations produced interacts with the negative charge on the cell wall and affects the membrane permeability. The nano-silver cations which have greater affinity towards sulphur and phosphorus containing compounds present in the outer membrane, respiratory enzymes, proteins and DNA, penetrate through the cell wall and plasma membrane by destabilizing them and cause protein denaturation by dissipating proton motive force, respiratory inhibition, intracellular ATP depletion and DNA damage [35].

5.2. Anti-Fungal Action:
The AgNPs exhibited antifungal action against various fungi . Actual mechanism behind the antifungal activity is not fully. The disrupting the structure of the cell membrane by destructing the membrane integrity, thereby the inhibition of the budding process has been attributed to be responsible for the antifungal action of AgNPs against *C. albanicans* species. The shape of the AgNPs has a significant effect on the anti-microbial activity [35].

5.3. Anti-Parasitic Action:
The AgNPs have been found to be effective larvicidal agents against dengue vector *Aedes aegypt*, and *Culex quinquefasciatus*[45], filariasis vector *C. quinquefasciatus* and malarial vector *A. subpictus*, *Aedes aegypti* , *A. subpictu* and other parasites[46].

5.4. Anti-Fouling Action:
The AgNPs synthesized from *Rhizopus oryzae* fungal species have been used for treating contaminated water and adsorption of pesticides [47]and that from *Lactobacillus fermentum* cells have been used as anti-bio fouling agent. The AgNPs are being used to treat many environmental concerns like; air disinfection, water disinfection, ground water and biological water disinfection and surface disinfection[48].

5.5. Antidiabetic Activity of AgNPs:
The ability of AgNPs synthesized using stem extracts of *Tephrosia tinctoria* to control blood sugar levels was evaluated. AgNPs scavenged free radicals, decreased levels of enzymes that catalyze the hydrolysis of complex carbohydrates (α-glucosidase and α-amylase), and increased the consumption rate of glucose [49].

5.6. Anticacer Activity of AgNPs:
The plant derived silver nanoparticles regulate the cell cycle and enzymes in bloodstream [50]. The green synthesis of silver nanoparticles exhibited a significant cytotoxic effect in HeLa cell lines compared to other chemical based synthetic drugs [9].

5. 6. Optics: Optoelectronic devices–active waveguides in optical devices (amplifiers)

5.7. Electronics : electronically conductive adhesives (ECAs)

5.8. Catalysis - the selective oxidation of alcohols, alkanes and alkenes - for the synthesis of industrially interesting products including water splitting degradation of organic pollutants[51].

5.9.Other uses:
Silver compounds are used in external preparations as antiseptics, including both silver nitrate and silver proteinate, which can be used in dilute solution as eye drops to prevent conjunctivitis in newborn babies. Silver nitrate is also sometimes used in dermatology in solid stick form as a caustic ("lunar caustic") to treat certain skin conditions, such as corns and warts. Silver is also used in bone prostheses, reconstructive orthopaedic surgery and cardiac devices. Chlorhexidine-silver-sulfadiazine central venous catheters significantly reduce the incidence of catheter-related bloodstream infections (CR-BSI). Silver diamine fluoride is an effective intervention to reduce dental caries (tooth decay).Silver acetate has been used as a potential aid to help stop smoking[51].

6. CONCLUSION:

Biosynthesis of silver nanoparticles using plant extracts is an excellent approach in green nanotechnology.The metabolites obtained from the plants induces the production of silver nanoparticles in eco-friendly manner. The plant mediated silver nanoparticles have the potential to be used in various fields such as pharmaceuticals, therapeutics and other commercial products. The plant derived silver nanoparticles have projected impact on diagnosis and treatment of various diseases with controlled side effects. In future, the plants have wide perspectives for synthesis of metallic nanoparticles in healthcare and commercial products. It can be concluded that the application of silver nanoparticles at a permissible level could be beneficial for Agriculture as well as in Pharmaceuticals.

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