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Green Synthesis of Silver Nanoparticles using Plants

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Introduction

Green principle route of synthesizing have emerged as alternative to overcome the limitation of conventional methods among which plant and microorganisms are majorly exploited. Employing plants towards synthesis of nanoparticles are emerging as advantageous compared to microbes with the presence of broad variability of bio-molecules in plants can act as capping and reducing agents and thus increases the rate of reduction and stabilization of nanoparticles [1].

Green synthesis approaches adhere to the basic principles of green chemistry *viz* i) Use of benign universally accepted solvent ii) Use of harmless capping agent and iii) the use of non-toxic or non-hazardous stabilizing agents. Green synthesis can be prepared using mixed-valence polyoxometalates, polysaccharides, tollens, biological, and irradiation. Biological methods of synthesis make use of the vast bioresources naturally available like plants, bacteria, fungi, yeast, viruses, cow milk, urine, enzymes and others [2].

Green synthesis possesses the following advantages over traditional chemical methods. (1) Green synthesis is simple and usually involves a one-pot reaction; (2) it is amenable to scale up; (3) the toxicity-associated hazardous chemicals are eliminated, increasing the biocompatibility of the resulting product with normal tissues for in vivo applications; and (4) green biological entities can be used as reducing agents and capping agents, providing with enhanced colloidal stability. (5) Finally, the process is cost-effective. These advantages are not limited to SNPs. There are extensive reviews regarding the applications of green-synthesized metallic NPs [2-4].

Green synthesis of silver nanoparticles using plants is rapidly gaining significant interests with overwhelming responses over the last decade. Research and development in this direction expanded after the first report of the used of alfalfa sprouts as a source of SNPs synthesis [5]. Thereafter, re-exploration of the vast traditional herbal medicinal plants as an important and reliable source towards an ecofriendly method of nanoparticles synthesis has been extensively exploited.

Ahmed et al. [6] had reported a simple one-pot green synthesis of stable silver nanoparticles using A. indica leaf extract at room temperature was reported in this study. Synthesis was found to be efficient in terms of reaction time as well as stability of the synthesized nanoparticles which exclude external stabilizers/reducing agents. It proves to be an eco-friendly, rapid green approach for the synthesis providing a cost effective and an efficient way for the synthesis of silver nanoparticles. Benefits of using plant extract for synthesis is that it is energy efficient, cost effective, protecting human health and environment leading to lesser waste and safer products.

Ahmed et al. [7] described one pot green synthesis of silver nanoparticle using *Terminalia arjuna* leaves extract has been reported. Silver nanoparticle has been successfully synthesized by this simple, fast, cost effective, environment friendly, efficient method. The synthesized silver nanoparticles showed efficient antimicrobial activities. The silver nanoparticles synthesized by this one pot green synthesis method will be proving of potential use in medical applications.

A number of plants are being currently investigated for their role in the synthesis of nanoparticles such as *Ocimum tenuiflorum*, *Solanum trilobatum*, *Syzygium cumini*, *Centella asiatica* and *Citrus sinensis* leaves [8], *Trianthema decandra* roots [9], *Ocimum sanctum* stems and roots [10], *Piper betle* [11], *Tinospora cordifolia* [12], *Morindaci trifolia* [13].

Mechanism of Synthesis

The green synthesis of SNPs is a simple and facile approach that is carried out by mixing silver nitrate (the silver ion source) with a biological entity (the reducing agent), other factors like an external source of energy, pH can be used to facilitate the reaction. Many researchers have used plants as both capping and stabilizing agent for synthesis of nanoparticles [2]. It is opined that the reduction and stabilization of silver ions is facilitated by combination of biomolecules such as proteins, amino acids, enzymes, alkaloids, tannins, phenolics, saponins, terpinoids, ketones, aldehydes, amides, carboxylic acids, steroids, sapogenins, carbohydrates, flavonoids and vitamins which are already established in the plant extracts having medicinal values and are environmental benign, yet chemically complex structures. Flavones, organic acids, and quinones are water-soluble phytochemicals that are responsible for the immediate reduction of the ions [14,2].

Though the exact mechanism involved in each plant varies as the photochemical involved varies, the major mechanism involved is the reduction of the ions. These phytochemicals are claimed to be the driving force for the reducing properties, which is very complex mechanism as there are more than 5000 phytochemical being identified [14]. Thus green synthesis of silver nanoparticles will require more comprehensive research as to unveil the exact biomolecules acting as the reducing or stabilizing agent. Nevertheless, Myriads of plants are reported to facilitate silver nanoparticles syntheses is well documented and it is rapidly growing further.

Silver Nanoparticles: The Broad Spectrum of Antimicrobials

Recent advances in silver nanotechnology help us to design and synthesize SNPs. Biosynthesis is best of all other synthesis processes of SNPs because of their nontoxic nature. Their unique optical, physical, and antimicrobial properties would lead SNPs wide spread uses in medical and different sectors like would healing, food sanitation, drug delivery etc. SNPs can also be used by integration with other materials to improve their properties like plasmonic light traps. These properties are useful in fuels, solar cells, micro- electronics, medical imaging and waste management. Further desired properties can be obtained by preparing composite by using SNPs as reinforcement into polymer matrix. Aggregation and toxic nature of silver nanoparticles limit its uses in some application. Future investigations should be preparation of SNPs which aim at overcoming these kinds of challenges and would be useful in designing effective drug delivery agent, diagnosing and treating fatal diseases besides ensuring higher safety and efficacy.

Research over last three decades has increased concern about the treatment of various types of wounds causes and their remedies. The major concerns which are threatening and spend worldwide are different types of microbial infections into them and are the major factor of amputations/ surgical removals of the different organs and sometimes death in all developed and well developing countries. Therefore, synthesis of nanosilver in combination with biomaterials will generate considerable interest in the field of medical science especially the domain of wound dressings. Silver shows the highest surface plasmon resonance band intensity than any other NPs like copper and gold. For having surface plasmon resonance effect both SNPs and Gold NPs are usually employed in optical detection. Since SNPs show sharper and stronger peaks of plasmon resonance than that of Gold NPs at the equal concentration of particles its efficiency of Plasmon efficiency is higher. For this reason SNPs impart better sensitivity for applications like surface enhanced Raman scattering or localized surface Plasmon resonance. Plasmon surface absorbance of gold NPs is in the wavelength range of 500 nm to 600 nm while most fluorophores emit above 500 nm. So quenching of some detectable fluorescence can occur when fluorescent dyes are adjacent to the surface of particle. This sort of fluorescence quenching is rarely occurred on the SNPs as surface absorbance of SNPs is mostly below than 500 nm. For this reason SNPs have stronger fluorescent signal than gold NPs [7].

Silver nanoparticles are reported to possess anti-fungal, anti-inflammatory, anti-viral, anti-angiogenesis, anti platelet activity besides effective antimicrobial agent against various pathogenic microorganisms. Bacterial growth inhibition around the well is due to the release of diffusible inhibitory compounds from silver nanoparticles. Smaller particles having the larger surface area available for interaction will give more bactericidal effect than the larger particles.

Many researchers investigated bactericidal efficacy of silver nanoparticles and their effective potential against broad range of microbes, including antibiotic-resistant bacteria. Silver nanoparticles are also termed as new-generation of antimicrobials [3,4]. Silver nanoparticles from *Ocimum tenuiflorum*, *Solanum tricobatum*, *Syzygium cumini*, *Centella asiatica* and *Citrus sinensis* were tested against *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Klebsiella pneumonia*. *O. tenuiflorum* extracts found significant activity against *S. aureus* (30 mm) and *E. coli* (30 mm) respectively [8].

SNPs synthesized using apple extract in suspension showed activity against Gram-negative and Gram-positive bacteria with minimum bactericidal concentrations (MBCs) to be in the range from 125 g/mL to 1000 g/mL. They have also shown that the range from 125 to 1000 g/mL was required to eliminate the Gram-positive and Gram-negative bacteria. *E. coli* required the lowest MBC which was 125 g/mL of SNPs. This green synthesis provides an economic, eco-friendly, and clean synthesis route to SNPs [15].

Das et al. [16] demonstrated that antimicrobial activity of silver nanoparticles synthesized using ethanolic extracts of *P. decandra*, *G. sempervirens*, *H. Canadensis* and *T. occidentalis*. The synthesis of silver nanoparticles using *Cassia auriculata* leaf extract was and evaluated for antimicrobial activity against *E. coli*, *Serratia marcescens*, *Bacillus subtilis*, *Aspergillus niger* and *Aspergillus flavus*. The photosynthesized silver nanoparticles using different plant parts (leaves, bark and root) of Avicenna marina mangrove plant showed the maximum silver nanoparticles formation than the bark and root extract [17]. It was observed that the antimicrobial effect was dose-dependent and increased linearly with the increased concentration of the test sample.

Silver Nanoparticles against Multidrug Resistant Bacteria

Recently, the increasing number of drug-resistant bacteria has become a major challenge endangering human health. SNPs have been also demonstrated as an effective biocide against these drug-resistant strains. Nanotechnology provides a good platform to overcome the emerging problem of multidrug resistance, with the help of the silver nanoparticles. Silver nanoparticles of size 10-100 nm have strong bactericidal potential against both Gram-positive and Gram-negative bacteria. Therefore, silver nanoparticles having bactericidal potential would be used as powerful weapons against the MDR bacteria. Nanda and Saravanan [18] reported the synthesis of silver nanoparticles by aqueous silver ion reduction with *Staphylococcus aureus*. These silver nanoparticles were evaluated for their antimicrobial potential against methicillin-resistant *Staph. aureus*, methicillin-resistant *Staph. epiderrmidis* (MRSE), *Strep. pyogenes*, *Salm. typhi* and Kl. pneumoniae.

Panacek et al. [19] synthesized silver nanoparticles by developing one-step protocol and evaluated their antimicrobial activity against Gram-positive and Gram-negative bacteria, including MDR strains such as MRSA. Silver nanoparticles can be used as effective broad-spectrum antibacterial agents for Gram-negative and Gram-positive bacteria, including antibiotic-resistant bacteria. Gram-negative bacteria include members of the genera *Acinetobacter, Escherichia, Pseudomonas, Salmonella* and *Vibrio*. Gram-positive bacteria include *Bacillus, Clostridium, Enterococcus, Listeria, Staphylococcus* and *Streptococcus*.

Future Prospects

Silver nanoparticles have gained significant interest due to their unique optical, antimicrobial, electrical, physical properties and their possible application. The change of energy level from continuous band to discrete band of SNPs with decrease in size of particles gives strong size dependent chemical and physical properties. SNPs show lower toxicity to human health while SNPs show higher toxicity to various microorganisms. For this reason SNPs having scope for medical instruments, antimicrobial application, products for health care such as scaffolds, burn dressing, water purification, agriculture uses. SNPs can be synthesized by using various methods that is primarily classified into two type's namely physical process, which includes laser ablation, condensation, evaporation etc., and chemical process that includes hydrazine, sodium borohydride, green synthesis etc. Among all these methods green synthesis is non-toxic, eco-friendly and cost effective [20].

The importance of SNPs have played pivotal role in inhibiting various infectious disease caused by microbes in combination with simultaneous helping in the burn wounds healing process, by preventing wound from infections caused by microbes. Furthermore SNPs are also known for their anti-inflammatory and antiviral activity. Apart from its widely known antimicrobial activity it has remarkable application in biological field as well as in other research fields such as electrochemistry, biochemistry, nanoprism synthesis, garments, detergents and soap industry, involved in devising water purification system, and surgical instrument. Moreover SNPs have a bright future in devices that can be used as artificial implants in future and minimizing the dependency on antibiotics. Recently researchers revealed novel biological application of SNPs; helpful in building new pharmaceutical and therapeutic agents. They used mouse model for the assessment of the anti-inflammatory effect. The full potential of this technology is yet to be investigated. A reliable mechanism responsible for the impressive biological activity of SNPs is yet to be established and is considered to be a key factor in future research. There is room for controlling the release of silver and improving the stability of SNPs used in various devices for various purposes especially in medicinal field [21].

Biosynthesis is best of all other synthesis processes of SNPs because of their nontoxic nature. Their unique optical, physical, and antimicrobial properties would lead SNPs wide spread uses in medical and different sectors like would healing, food sanitation, drug delivery etc. SNPs can also be used by integration with other materials to improve their properties like plasmonic light traps. These properties are useful in fuels, solar cells, micro- electronics, medical imaging and waste management. Further desired properties can be obtained by preparing composite by using SNPs as reinforcement into polymer matrix. Aggregation and toxic nature of silver nanoparticles limit its uses in some application. Future investigations should be preparation of SNPs which aim at overcoming these kinds of challenges and would be useful in designing effective drug delivery agent, diagnosing and treating fatal diseases besides ensuring higher safety and efficacy.

Conclusion

Thus, with observed excellent antibacterial properties, SNPs have been suggested as effective broad-spectrum biocides against a variety of drug-resistant bacteria. Further the nanoparticles syntheses by green route are found highly toxic against multidrug resistant human pathogenic bacteria. However, before implementing the various applications of silver nanoparticles, it is necessary to investigate the potential toxicological impacts of silver nanomaterials. SNPs are attractive because they are non-toxic to the human body at low concentrations and have broad- spectrum antibacterial action.

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