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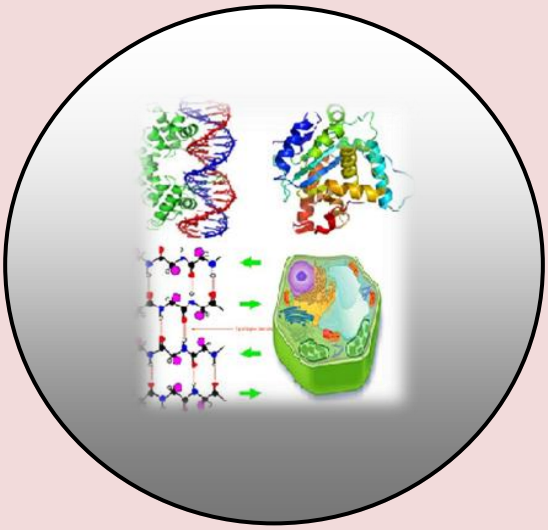

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Synthesis and Applications of Biogenic Silver Nanoparticles

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ABSTRACT

Silver nanoparticles (AgNPs) have gained significant interest due to their unique optical, antimicrobial, electrical, physical properties and their possible application. The AgNPs may be synthesized by various chemical and physical methods; however, most of these methods are energy consuming, costly and environment harming. Hence, researchers are much interested in preparing NPs by biological methods, also called as Green-Approach of NP synthesis. In past decades, the researchers have developed methodologies that incorporate the use of biological entities such as algae, bacteria, fungi, yeasts, and plants in a number of biochemical and biophysical processes for the synthesis of NPs. These methods are cost effective, eco-friendly and faster than most of the physical and chemical methods of NP synthesis. In this review, the green synthesis, properties, applications of silver nanoparticles and their recent advances are described.

Keywords: Silver Nanoparticles, Biogenic Synthesis, Antimicrobial Property and Mycogenic Synthesis.

INTRODUCTION

In recent time, noble metal nanoparticles (NPs) are the materials of focused research due to their unique optical, electronic, mechanical, magnetic, and chemical properties that are significantly different from those of bulk materials (Mazur, 2004). These unique properties of NPs are due to the smaller size and larger surface area, due to which NPs are applicable in the various fields of sciences like physics, chemistry, agriculture, environment, medicine etc. Synthesis of silver NPs (AgNPs) is the matter of great interest of recent researchers due to its properties like magnetic and optical polarizability (Shiraishi and Toshima, 2000), electrical conductivity (Chang and Yen, 1999), catalysis (Shiraishi and Toshima, 2000), antimicrobial and pesticidal properties (Baker et al, 2005; Shahverdi et al, 2007), DNA sequencing (Cao et al, 2001) and surface-enhanced Raman scattering (SERS) (Matejka et al, 1992).

Synthesis methods

Any techniques of synthesizing silver nanoparticles, such as chemical reduction of silver ions in aqueous solutions with or without stabilizing agents (Liz-Marzan and Lado-Tourino, 1996), thermal decomposition in organic solvents (Esumi et al, 1990), chemical reduction and photo-reduction in reverse micelles (Pileni, 2000; Singaravelu et al, 2007) and radiation chemical reduction have been reported (Henglein, 1993; Henglein, 1998; Henglein, 2001). The bio-synthesis of AgNPs was first of all performed during early 20th century and AgNPs of size up to 25 nm were prepared by using fungus *Verticillium* (Mukherjee et al, 2001a and 2001b). Synthesis using *Verticillium* is a green approach of NP preparation. Several reports have explained the bacterial synthesis of NPs; in one such report the synthesis of AgNPs by *Pseudomonas stutzeri* AG259 was provided (Esumi et al, 1990). The fungal biomass filtrate mediates the formation of AgNPs by $AgNO_3$.

Green synthesis of nanoparticles

The NPs synthesized by the fungi are not prepared in the solution but adsorbed on the surface of mycelia. It was then suggested that the produced Ag+ are adsorbed on the surface of mycelia due to ionic bonding between negatively charged COOH - groups in enzymes present in the cell wall of mycelia. Finally, the Ag+ is reduced by the enzymes present on the cell wall, to form silver nuclei (Mukherjee et al, 2001). Compared to bacteria, fungi are known to secrete much higher amounts of proteins, which tends to significantly increase the productivity of this biosynthetic approach; moreover, fungi could be used for the production of large amounts of metal nanoparticles.

Extra/Intracellular Biosynthesis of Nanoparticles

Ahmad et al. (2003) first of all reported the extracellular biosynthesis of AgNPs and said that the secreted enzymes are responsible for catalyzing the biosynthesis. Before this report, only intracellular synthesis was popular. The extracellular synthesis is more convenient as it leads to easy purification of NPs (Ahmad et al, 2003; Balaji et al, 2009). The biosynthesis of NPs by fungi is an eco-friendly or green-approach as no harmful by-products are formed. The non-pathogenic fungi may be used for synthesis of AgNPs (Duran et al, 2005). The fast reaction rate of NP synthesis is also a significant aspect of biosynthesis of NPs by fungi. The synthesis of AgNPs within 10 minutes time by *Aspergillus fumigatus* was reported in a study (Vigneshwaran et al, 2006). The common molds *Aspergillus fumigatus* cell filtrate can be used to synthesize AgNPs in a minute time. Recently, *A. flavus* synthesized AgNPs were used in combination with antibiotics to enhance the biocidal efficiency against multidrug-resistant bacteria (Bhainsa and D'Souza, 2006). Hence, all these studies suggest promising significance of fungi to be used for bio-synthesis of AgNPs.

Similar to molds, various species of yeast have also been studied for synthesis of AgNPs (Mourato et al, 2011; Naqvi et al, 2013). Silver-tolerant yeast strain MKY3 was first of all used for the extracellular synthesis of NPs and this approach was found to be simple and reliable as the purification of NPs was more feasible (Apte et al, 2013). All the aggravating steps of cultivation of the yeast were avoided, thus making the process much simpler (Kowshik et al, 2003). Similar to moving from prokaryotes to eukaryotes green synthesis, the utilization of eukaryotic autotrophs widened the possibilities of green synthesis. For example, using marine algae *Sargassum wightii* allowed obtaining very stable nanoparticles compared to other biological methods (Saravanan et al, 2014).

Environmentally sustainable synthesis

The chemical and physical synthesis methods for NPs preparation are costly, bio-hazardous and generally cause generation of toxic by-products. Hence, the green-approach of NP synthesis is more acceptable as it is cost effective and eco-friendly. The study of applications of biological materials or formulations for synthesis of materials is called as Biomimetics. Bio-reduction is a fundamental approach under biomimetics for production of materials. Hence, the biological synthesis approaches like production of NPs by fungi, bacteria and plant is being widely accepted.

Antimicrobial Efficacy

The multi-drug resistant pathogens are more recalcitrant microorganisms and offering greater challenge to the researchers. Hence, researchers are looking for approaches and mechanisms to prepare drugs that can be used against these microorganisms. Nanotechnology can be expected to be an efficient tool for disease and pest-management. AgNPs have been well known for its microbicidal and insecticidal properties.

Therefore antimicrobial silver is being used as an ointment in wounds and burns. It is effective because the pathogen is unable to mutate in order to develop resistance against the pathogens.

CONCLUSION

Nanotechnology is a new science with vast range of scopes and applications in various areas *viz* physics, chemistry, agriculture, environment, medicine etc. The green synthesis methods for nanoparticles' synthesis are cost-effective and eco-friendly as compared to physical or chemical synthesis methods. Hence, biological synthesis approaches must be encouraged and followed for the synthesis of nanoparticles.

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