



Biomechanistic Approach of Nanoparticle Synthesis using Microbes

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Introduction

Nanotechnology has advanced dramatically over the last few decades, as a result of the diverse applications of metal nanoparticles in various fields such as biology, food, agriculture, engineering, electronics, cosmetics, medicine, and biomedical devices (Slavin et al., 2017). Many scientists have developed metal nanoparticles using traditional physical and chemical methods over the last decade. The downsides of the physical technique include high synthesis costs and low yield. Similarly, chemical procedures are risky due to the presence of toxic chemical compounds adhering to the surface of metal nanoparticles, which have negative side effects in biomedical applications. Given the aforementioned concerns, research has switched toward the synthesis of metal nanoparticles employing biological ingredients that are cost-effective, biocompatible, non-toxic, and environmentally friendly (Ovais et al., 2018). In the biological process, nanoparticles are synthesized using plants and microbes. The downside of phyto-genic nanoparticle synthesis is the generation of polydisperse nanoparticles. Therefore, a new strategy has been developed for the synthesis of nanoparticles using microbes such as bacteria, fungi, algae, and others. Metal nanoparticles and their alloys (gold, silver, gold-silver alloy, selenium, tellurium, platinum, palladium, silica, titania, zirconia, quantum dots, magnetite, and uraninite) have been biosynthesized in bacteria, actinomycetes, fungi, yeasts, and viruses. The present article describes the biomechanistic approach of nanoparticle synthesis using different microorganisms.

Mechanism of biosynthesis of nanoparticles using microbes

The mechanism of biosynthesis involves an intracellular and extracellular approach in microbes. In the intracellular pathway, the metal ions are attracted towards the positively charged cell membrane and are encapsulated inside the cell, which are then reduced to respective nanoparticles which is carried out by



bacterial cell enzymes. In case of the extracellular approach, the microbial cell secretes certain reductases which are responsible for the bioreduction of the metal ions into the nanoparticles which occurs in the extracellular space (Hulkoti and Taranath, 2014).

Synthesis of nanoparticles using bacteria and cyanobacteria

The synthesis of nanoparticles in bacteria and cyanobacteria is carried out using both intracellular and extracellular approaches. However, the extracellular approach is preferred over the other. A study reported the synthesis of silver nanoparticles using the bacterium *Bacillus brevis* exhibiting antimicrobial activity against the *Staphylococcus aureus* and *Salmonella typhi* (Saravanan et al., 2014). Another study reported the use of *Halomonas elongate* for the synthesis of copper nanoparticles which had a triangular shape and were active against *E. coli* and *S. aureus* (Rad et al., 2018). Not only antibacterial but nanoparticles having anticancer effects such as super paramagnetic iron oxide nanoparticles were synthesized using *Bacillus cereus*

Cyanobacteria has been used for the synthesis of nanoparticles which include synthesis of silver nanoparticles by using ammonia sensing cyanobacteria. A marine cyanobacteria called *Phormidium fragile* was used for the synthesis of silver nanoparticles having hydrodynamic diameter of 5-6.5 nm.

Synthesis of nanoparticles using fungi

The synthesis of nanoparticles using fungi also involves the intracellular and extracellular pathway. The intracellular synthesis of nanoparticles involves the conversion of highly toxic metal salts to less toxic metal nanoparticles in the mycelia, while the extracellular pathway involves the use of fungal extracts. The fungal method of nanoparticle synthesis is more advantageous as compared to the use of bacteria due to the high presence of bioactive metabolites, higher yield and accumulation. In one study, gold nanoparticles were synthesized from fungal strains such as *Aureobasidium pullulan* and *Fusarium oxysporum* (Zhang et al., 2011). These nanoparticles were synthesized in fungal vacuoles in which reducing sugars were involved in the synthetic process. Zinc oxide nanoparticles were synthesized using *Aspergillus niger* which showed the potential of degrading Bismarck brown dye. *Candida glabrata* was used for the extracellular synthesis of silver nanoparticles.

Synthesis of nanoparticles using algae

Zinc oxide nanoparticles were synthesized using *Sargassum mutichich* exhibited anti-angiogenic effects in the HepG2 cell line. Antimicrobial activity exhibiting silver nanoparticles were synthesized using *Gelidium amansii* (Sanaeimehr et al., 2018). Copper nanoparticles having hydrodynamic diameter of 7 nm using *Cystoseira trinodis* having antioxidant potential degrading the methylene blue (Gu et al., 2018).



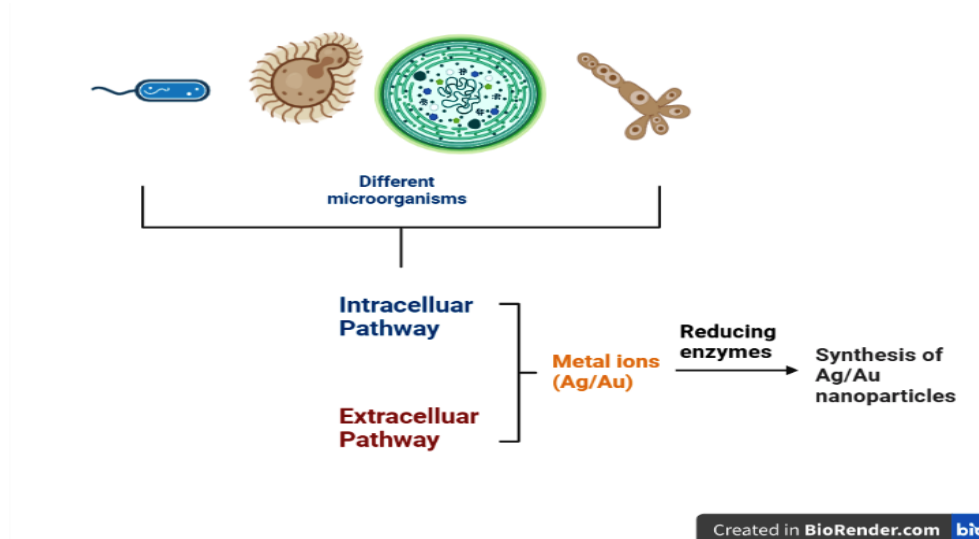


Fig. 1: Schematic representation of the biosynthetic mechanism of nanoparticle synthesis using microorganisms [Picture created using an online tool (biorender)]

Synthesis of nanoparticle using extracellular microbial enzymes

Extracellular microbial enzymes have been shown to be important reducing agents in the formation of metal nanoparticles. According to research, cofactors such as nicotinamide adenine dinucleotide (NADH) and reduced form of nicotinamide adenine dinucleotide phosphate (NADPH) dependent enzymes both play critical roles as reducing agents via electron transfer from NADH by NADH-reliant enzymes that act as electron carriers. The bacteria *Rhodopseudomonas capsulata* synthesized gold nanoparticles extracellularly via the secretion of NADH and NADH-reliant enzymes. Gold bioreduction begins with electron transfer from NADH by NADH-reliant reductase enzymes found in *R. capsulata*. As a result, gold ions receive electrons and undergo reduction (Au^{3+} to Au^0), resulting in the production of gold nanoparticles (He et al., 2007).

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