Nanobiosynthesis

Synthesis of nanoparticles by fungi

Throughout human history, fungi have been utilized as a source of food and harnessed to ferment and preserve foods and beverages.

In the 20th century, humans have learned to harness fungi to protect human health (antibiotics, anti-cholesterol statins, and immunosuppressive agents), while industry has utilized fungi for large scale production of enzymes, acids, and biosurfactants.

With the beginning of modern nanotechnology in the 1980s, fungi have remained important by providing a greener alternative to chemically synthesized nanoparticle.

The most common nanoparticles synthesized by fungi are silver and gold, however fungi have been utilized in the synthesis other types of nanoparticles including zinc oxide, platinum, magnetite, zirconia, silica, titanium, and cadmium sulfide and cadmium selenide quantum dots.

Silver nanoparticle production

Extracellular systhesis has been demonstrated by *Trichoderma virde*, *Aspergillus niger*, *Penicillium brevicompactum*,

while intracellular synthesis was shown to occur in a *Verticillium* species, and in *Neurospora crassa*.

Gold nanoparticle production

Extracellular gold nanoparticle synthesis was demonstrated by *Fusarium oxysporum*, *Aspergillus niger*, and *Candida albican*.

Intracellular gold nanoparticle synthesis has been demonstrated by a *Verticillum* species.

Miscellaneous nanoparticle production

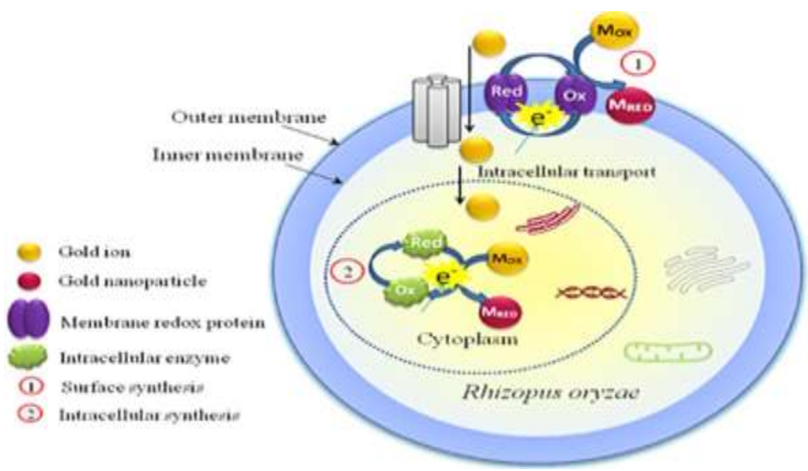
In addition to gold and silver, *Fusarium oxysporum* has been used to synthesize zirconia, titanium, cadmium sulfide and cadmium selenide nanosize particles.

Cadmium sulfide nanoparticles synthesized by *Trametes versicolor*, and *Candida glabrata*.

Gold and silver Formation mechanisms

Nitrate reductase was suggested to initiate nanoparticle formation by many fungi including *Penicillium* species, while several enzymes, α-NADPH-dependent reductases, nitrate-dependent reductases were implicated in silver nanoparticle synthesis for *Fusarium oxysporum*.

External gold nanoparticle synthesis was attributed to laccase, while intracellular gold nanoparticle synthesis was attributed to ligninase.



Intracellular silver and gold nanoparticle synthesis are not fully understood, but similar fungal cell wall surface electrostatic attraction, reduction, and accumulation has been proposed.

Fungi		Bacteria
High/Very high (Rajapaksha *et al.*, 2004)	Metal toxicity resistance	Medium/High (Rajapaksha *et al.*, 2004)
Commonly extracellular (Durán *et al.*, 2011)	AuNP location	Both intracellular and extracellular (Lengke and Southam, 2006)
Very fast in cell-free filtrate (<1 h) (Du *et al.*, 2011)	Biosynthesis rate	Relatively slow (>24 h) (Du *et al.*, 2011)
Shape and size depend on biomass/Au ratio (Pimprikar *et al.*, 2009)	AuNP shape and size	Prevalently spherical, small AuNPs (Wen *et al.*, 2009)
NADH-reductases, phytochelatins, melanin (Mukherjee *et al.*, 2001)	Bioreducing agent(s)	Microbially produced redox mediators, membrane proteins and cytochromes, inorganic redox compounds (von Canstein *et al.*, 2008; Marshall *et al.*, 2008; Mukherjee *et al.*, 2002)
Unidentified surface-bound proteins (Shankar *et al.*, 2003; Das *et al.*, 2009)	Bio-capping agent(s)	Not yet identified
More likely	Scalability to industrial process	Less likely

Fusarium oxysporum has also been shown to produce Cadmium sulfide (CdS), lead sulfide (PbS), zinc sulfide (ZnS), and molybdenum sulfide (MoS) nanoparticles when the appropriate salt is added to the growth medium.

A later study on the production of AgNPs was done by used *Aspergillus fumigatus* to synthesize extracellular silver nanoparticles in the size range of 5-25 nm. This range in size was larger than previously reported by *F. oxysporum*, which might cause a disadvantage when application predictability comes into play, as it would be difficult to predict the catalytic activity of the nanoparticles produced if their sizes are different in every batch.

Advantages of fungal biosynthesis of nanoparticles

Fungi are more advantageous compared to other microorganisms in many ways:

 Fungi could be a source for large amount production of nanoparticles because they are known to secrete much higher amounts of proteins, thus might have significantly higher productivity of nanoparticles in biosynthetic approach compared with bacteria.

 Because of their tolerance and metal bioaccumulation ability, fungi are taking the center stage of studies on the biological generation of metallic nanoparticles.

Fungi are extremely efficient secretors of extracellular enzymes; it is thus possible to easily obtain large-scale production of enzymes. It is economic viability and ease in handling biomass.

Disadvantages of fungal biosynthesis of nanoparticles

 A majority of the filamentous fungi (eg, *Aspergillus fumigatus*) that have reportedly been used for extracellular biomass free synthesis of AgNPs are pathogenic to plants and/or humans. Thus, there is a need for developing a newer/ novel approach to testing a nonpathogenic fungus for the successful synthesis and capping of nanosized silver particles.

 The genetic manipulation of eukaryotic organisms as means of over expressing specific enzymes (eg, the ones identified in synthesis of metallic nanoparticles) is relatively much more difficult than that in prokaryotes.