Nanoparticles Emerging Through Microbial Routes

Chandan Sharma, Pranav Tripathi# and Nitya Wadhwa

Translational Health Science and Technology Institute, Faridabad

# Corresponding author

ABSTRACT

Green nanotechnology, characterized by reduced toxicity and environmental compatibility, leverages microorganisms for nanoparticle synthesis. This review delves into microbial mechanisms in nanoparticle production. Fungi like *Saccharomyces cerevisiae, Candida glabrata,* and *Fusarium oxysporum* employ distinct enzymatic pathways for synthesis. *Aspergillus spp* and *Pleurotus ostreatus* demonstrate diverse enzymatic and reducing agent routes. Bacteria, notably *Rhodopseudomonas palustris* and *Bacillus thuringiensis*, contribute through lyases and bioreduction, respectively. *Cyanobacteria* display bioaccumulation tendencies yielding gold nanoparticles, while *Rhodopseudomonas palustris* reveals cellular-nanoparticle dynamics. This exploration illuminates the potential of microorganism-mediated nanoparticle synthesis for sustainable applications, providing insights into mechanisms and interactions.

Keywords— Green nanotechnology, nanoparticle synthesis, microorganisms, fungi, bacteria, enzymatic pathways, reducing agents, environmental compatibility, sustainable applications, bioaccumulation, cellular dynamics.

# INTRODUCTION

Despite of having tangible progress in the field of synthesis of nanoparticles (1) (2) (3) (4), green nanotechnology(5) has emerged as an attractive feature with a reduction in toxicity values and ameliorating potential for environmental issues (6). Green nanotechnology uses microbial entities for the synthesis of nanoparticles. Many microorganisms and plants store or accumulate various inorganic materials inside or outside the cell and this property can be exploited to synthesize nanoparticles (7). The studies on enzyme structure and nucleic acids that code for these specific enzymes can demystify the mystery regarding synthesis of nanoparticles (8). Metal ions are reduced to nanoparticles by cell walls (9) and cell wall proteins of microorganisms and due to advancements in techniques infer the application of nanoparticles in a variety of fields on the basis of composition, shape, size and molecular interactions. In this article emphasis is laid on the microorganisms that can be employed for synthesis of nanoparticles along with a brief glimpse of their mechanism.

# BIOSYNTHESIS USING FUNGI

Fungi have been extensively employed for the biosynthesis of nanoparticles and the mechanistic aspects controlling the nanoparticle formation have also been deduced for a few. Contrasting to bacteria, fungi could be used as a source for mass production of nanoparticles. This is due to the piece of evidence that fungi exude more amounts of proteins which directly decipher increased productivity of nanoparticle formation (**10**). In addition to dispersity in single dimension, nanoparticles with well illustrated dimensions can be acquired by using fungi.

In case of biosynthesis of gold nanoparticles by *V.luteoalbum*, the rate of nanoparticle formation and their size can be manoeuvred using physical parameters like pH, temperature, gold exposure time and concentration. (11).

## Biosynthesis by Saccharomyces cerevisiae and Candida glabrata:

Nature has provided yeasts and some other fungus with membrane bound oxidoreductases and cytosolic oxidoreductases along with quinines ( 12) (13). These oxidoreductases and quinones (14) are supposed to be the reason for reduction of inorganic substances to nanoparticles (15 ). Oxidoreductases are pH sensitive enzymes with a specific ability to work as oxidases at low pH and reductases at high pH (16) (17). The method to synthesize nanoparticles involves generation of stress. During such stressful conditions transformation takes place and this transformation is subjected to strictness at two distinct levels. At cell membrane level, as TiO(OH)2 is added tautomerization of quinones and oxidases takes place. In a similar study with *Candida glabrata*(18.), where stress was provided using Cd ions and the tautomerization has deduced an elaboration of phytochelatin synthase (19) and HMT-1 (20) which further helped in synthesis of CdS nanoparticles from the microbe (21). Secondly, if the TiO(OH)2 reaches cytosol, a family of oxygenases are activated in the endoplasmic reticulum, mainly responsible for detoxification using the process of oxygenation. The action as reductases releases derivatives of compounds popularly known as benzoquinones (22) and toluquinones (23). The above mentioned methodologies have been employed for the synthesis of metallic nanoparticles of titanium, silver and cadmium (24).

## **Biosynthesis by Fusarium oxysporum:**

Inferences from protein assays have pointed towards NADH-dependent reductase as key factor for biosynthesis processes. The enzyme oxidizes NADH to NAD+ by gaining electrons from NADH. Further, this enzyme gets oxidized by metal ion reductions. *Fusarium oxysporum* was used to synthesize 10-25 nm silver hydrosol by the above mentioned enzyme of molecular weight 44 kDa (25). Action of napthoquinones (26) and anthraquinones (27) as redox centres for the reduction of Ag nanoparticles has also been demonstrated (28).

Conjectures from various assays for nitrate dependent reductases (29) show that the reduction potential can be utilized for the synthesis of nanpoparticles. In *Fusarium oxysporum* quinine conjugates this enzyme and reduces the metal ion to change it to elemental form (30). Interestingly, *Fusarium monoliformae* that has extracellular and intracellular reductases in the same trend as *Fusarium oxysporum* is unable to synthesize nanoparticles. The possible reason could be that reductases from *Fusarium monoliformae* are fruitful for conversion of only Fe3+ to Fe2+ not Ag+ to Ag0 (31).

## **Biosynthesis by Aspergillus:**

*Aspergillus flavus* (32) (33.) upon challenging with silver nitrate has been found to mount up silver nanoparticles on the surface of its cell wall. The nanoparticles thus formed were monodispersed nanoparticles of size range 8.92+/-1.61 nm (34). *Aspergillus flavus* secretes some proteins and reducing agents that help to stabilize the nanoparticlees in extracellular state. Four high molecular proteins were found to be released by *Aspergillus flavus* in alliance to these nanoparticles (35) (36). *Aspergillus niger* also employed to synthesize silver nano particles of size 3-30 nm and nitrate reductase appeared to be a key mechanistic aspect (37) (38).

## **Biosynthesis by Pleurotus ostreatus:**

*Pleurotus ostreatus* after getting challenged from 1mM silver nitrate exuded the synthesis of silver nanoparticles. The presence of NADH dependent nitrate reductase (39) in cell filtrate provided the evidence for hypothesizing the mechanism for conversion of Ag(NO3)2to Ag nanoparticles (40) (41.).

# Biosynthesis using bacteria

Bacteria are considered to be a potent biomass for nanoparticles synthesis. Production of gypsum and calcium carbonate from S layer bacteria and production of magnetic nanoparticles from magnetotactic bacteria are well known demonstrations (42). Growth and survival of some microorganisms has been observed even at high metal ion concentrations, this survival may be the result of high level of tolerance or resistance developed in microorganisms. The reason for tolerance could be various efflux systems, bioaccumulations, removal of toxicity by reduction or oxidation or deficiency of metal transport systems (43).

## **A. Biosynthesis by Rhodopseudomonas palustris:**

Cadmium sulfide nanoparticle synthesis was revealed using *Rhodopseudomonas palustris* (44) by lyases class of enzymes. Systematically D-cysteine sulfide-lyase, which participates in cysteine metabolism, could be the key cause of this synthesis (45). The maximum absorbance peak at 425 nm demonstrated the quantum size organization of CdS particles. The causal enzyme was located in cytoplasm and *Rhodopseudomonas palustris* was found quite efficient in transporting CdS nanoparticles out of cell (46).

## **Biosynthesis by Bacillus thuringiensis:**

Growth of multi drug resistant strains of *Streptococcus aureus , Pseudomonas aeruginosa* and *Escherichia coli* were inhibited by use of silver nanoparticles synthesized by utilizing bioreduction property of *Bacillus thuringiensis.* The spore crystal mixture was shown to have bioreduction property by converting silver nitrate solution to yellowish silver nanoparticles (47).

## **Biosynthesis by Cyanobacteria:**

A cyanobacterium (*Plectonema boryanum* UTEX 485) was reported to synthesize gold nanoparticles by their tendency towards bioaccumulation. Documentations reveal that cyanobacteria upon interaction with gold(III)-chloride solution initially resulted in accumulation of gold(I)-sulfide (48). Further treatment resulted into formation of octahedral (III) platelets. Interestingly, *Plectonema boryanum* UTEX 485 when interacted with Au(SO4)23- gold nanoparticles of size 10-25 nm were accumulated in the solution whereas particles of size <10 nm were accumulated inside the cell. But the presence of AuCl4- solution resulted in octahedral gold platelets of size 1-10 micrometer and particles of size <10 nm inside the cell (49). Cyanobacteria were also incorporated in biological synthesis of palladium (50), silver (51) and platinum (52) nanoparticles.

.

# CONCLUSIONS

The use of microbes as means to synthesize nanoparticles has provided a vast insight into environment friendly approaches along with opening gates for various other approaches towards micro interactions of nanoparticles with proteins. Here the emphasized microbial entities use distinct communities of enzymes for synthesis purpose. Various oxidareductases, nitrate reductases and lyases result into synthesis of different nanoparticles with definite microbial and industrial possibilities. The synthesis using *Aspergillus* incorporated the use of four proteins and these proteins can be employed to study micro-interactions of nanoparticles. Synthesis using cyanobacteria has revealed a fact that the size of nanoparticles accumulated inside the cell are independent of solution used. Whereas, the aggregating or agglomerating property of nanoparticles is quite dependent on the type of solution used as 10-25 nm particles were formed using Au(SO4)23- and octahedral platelets formed by aggregation or agglomeration in AuCl4-. Lastly, the transfer of nanoparticles from cytoplasm to extracellular space in *Rhodopseudomonas palustris* illustrates the membrane structure that favors the to and fro motion of nanoparticles.

##### REFERENCES

1. Choi, R., Choi, S.I., Choi, C.H., Nam, K.M., Woo, S.I., Park, J.T., Han, S.W. [Designed Synthesis of Well-Defined Pd and Pt Core-Shell Nanoparticles with Controlled Shell Thickness as Efficient Oxygen Reduction Electrocatalysts.](http://www.ncbi.nlm.nih.gov/pubmed/23613263) Chemistry.2013;
2. Fuchs, A.V., Kotman, N., Andrieu, J., Mailänder, V., Weiss, C.K., Landfester, K. [Enzyme cleavable nanoparticles from peptide based triblock copolymers.](http://www.ncbi.nlm.nih.gov/pubmed/23612962) Nanoscale.2013;
3. Zhang, S., Ren, F., Wu, W., Zhou, J., Xiao, X., Sun, L., Liu, Y., Jiang, C. [Controllable synthesis of recyclable core-shell γ Fe2O3 and SnO2 hollow nanoparticles with enhanced photocatalytic and gas sensing properties.](http://www.ncbi.nlm.nih.gov/pubmed/23612776) Phys.Chem.Chem. Phys. 2013;
4. Kamińska, I., Sikora, B., Fronc, K., Dziawa, P., Sobczak, K., Minikayev, R., Paszkowicz, W., Elbaum, D. [Novel ZnO/MgO/Fe2O3 composite optomagnetic nanoparticles.](http://www.ncbi.nlm.nih.gov/pubmed/23612042) J. Phys.Condens. Matter. 2013; 25(19).
5. Wong,S.,Karn, B. Ensuring sustainability with green nanotechnology. Nanotechnology. 2012;
6. MohamadRusopMahmood, Tetsuo Soga, Mohamad Hafiz Mamat, ZuraidaKhusaimi and AsiahMohd Nor; Ropisah Mie et al. A Review on Biosynthesis of Nanoparticles Using Plant Extract: An Emerging Green Nanotechnology; Advanced Materials Research, 2013, 667, 251
7. Schwertfeger, D.M., Hendershot, W.H. [Toxicity and metal bioaccumulation in hordeum vulgare exposed to leached and non-leached copper amended soils.](http://www.ncbi.nlm.nih.gov/pubmed/23606189) Environ Toxicol Chem., 2013 Apr 18.
8. Bali, R., Razak, N., Lumb, A., Harris, A.T. The synthesis of metal nanoparticles inside live plants.,2006; IEEE Xplore DOI 10.1109/ICONN.2006.340592
9. Singh, R., Bishnoi, N.R., Kirrolia, A. [Evaluation of Pseudomonas aeruginosa an innovative bioremediation tool in multi metals ions from simulated system using multi response methodology.](http://www.ncbi.nlm.nih.gov/pubmed/23612183) Bioresour Technol., 2013 Mar 27;138C:222-234.
10. Mohanpuria, P.; Rana, K.N., Yadav, S.K. Biosynthesis of nanoparticles: technological concepts and future applications. Journal of Nanoparticle Research 10.,2008; 507- 517
11. Gericke, M., Pinches, A. Biological synthesis of metal nanoparticles. Hydrometallurgy 83.,2006; 132-140
12. Nelson, D.N., Cox, M.M.:Lehninger principles of Biochemistry:Freeman publications, NY., 2005; pp 798
13. Faletrov, Y.V., Frolova, N.S., Hlushko, H.V., Rudaya, E.V., Edimecheva, I.P., Mauersberger, S., Shkumatov, V.M. [Evaluation of fluorescent probes Nile Red and 25-NBD-cholesterol as substrates for steroid-converting oxidoreductases using pure enzymes and microorganisms.](http://www.ncbi.nlm.nih.gov/pubmed/23551929) FEBS. J. ,2013 Mar 28; doi: 10.1111/febs.12265
14. Madeo, J., Zubair, A., Marianne, F. [A review on the role of quinones in renal disorders.](http://www.ncbi.nlm.nih.gov/pubmed/23577302) Springerplus., 2013 Dec;2(1):139.
15. Gericke, M., Pinches, A. Biological synthesis of metal nanoparticles. Hydrometallurgy 83.,2006; 132-140.
16. Morgan, B., Ezeriņa, D., Amoako, T.N., Riemer, J., Seedorf, M., Dick, T.P. [Multiple glutathione disulfide removal pathways mediate cytosolic redox homeostasis.](http://www.ncbi.nlm.nih.gov/pubmed/23242256) Nat. Chem. Biol., 2013 Feb;9(2):119-25. doi: 10.1038/nchembio.1142
17. Durigon, R., Wang, Q., Ceh Pavia, E., Grant, C.M., Lu, H. Cytosolic thioredoxin system facilitates the import of mitochondrial small Tim proteins. EMBO. Rep., 2012 Oct;13(10):916-22. doi: 10.1038/embor.2012.116
18. Holmes, A.R., Keniya, M.V., Ivnitski-Steele, I., Monk, B.C., Lamping, E., Sklar, L.A., Cannon, R.D. [The monoamine oxidase A inhibitor clorgyline is a broad-spectrum inhibitor of fungal ABC and MFS transporter efflux pump activities which reverses the azole resistance of Candida albicans andCandida glabrata clinical isolates.](http://www.ncbi.nlm.nih.gov/pubmed/22203607) Antimicrob. Agents. Chemother., 2012 Mar;56(3):1508-15. doi: 10.1128/AAC.05706-11
19. Rigouin, C., Nylin, E., Cogswell, A.A., Schaumlöffel, D., Dobritzsch, D., Williams, D.L. [Towards an understanding of the function of the phytochelatin synthase of Schistosoma mansoni.](http://www.ncbi.nlm.nih.gov/pubmed/23383357) PLoS. Negl. Trop. Dis., 2013 Jan;7(1):e2037. doi: 10.1371/journal.pntd.0002037.
20. Kim, S., Selote, D.S., Vatamaniuk, O.K. [The N-terminal extension domain of the C. elegans half-molecule ABC transporter, HMT-1, is required for protein-protein interactions and function.](http://www.ncbi.nlm.nih.gov/pubmed/20886084) PLoS. One., 2010 Sep 23;5(9):e12938. doi: 10.1371/journal.pone.0012938.
21. Ortiz, D.F., Ruscitti, T., McCue, K.F., Ow, D.M. Transport of metal binding peptides by HMT-1, a fission yeast ABC type vacuolar membrane protein. J .Biol. Chem.,1995; 270:4721-4728
22. Qian, Y., Wang, W., Boyd, J.M., Wu, M., Hrudey, S.E., Li, X.F. UV-induced transformation of four halobenzoquinones in drinking water. Environ. Sci. Technol., 2013 Apr 5.
23. Packter, N.m., Glover, J. [Biosynthesis Of Toluquinones In Microorganisms.](http://www.ncbi.nlm.nih.gov/pubmed/14323649) Biochim .Biophys. Acta., 1965 Apr 12;100:57-64
24. Prasad, K., Jha, A.K. Lactobacillus synthesis of titanium nanoparticles, Nanoscale. Res. Lett., 2 (2007); 248-250
25. Sadowski, Z., Maliszewska, I., Polowczyk, I., Kozlecki, T., Grochowalska, B. Biosynthesis of colloidal-silver particles using microorganisms. Polish. J. Chem., 2008;82, 377-382
26. Senapati, S., Ahmad. Extracellular biosynthesis of bimetallic Au-Ag alloy nanoparticles. Small 1.,2005; 517-520
27. [Komada, H.](http://www.cabdirect.org/search.html?q=au%3A%22Komada%2C+H.%22) Development of a selective medium for quantitative isolation of Fusarium oxysporum from natural soil. [Review. Of. Plant. Protection. Research](http://www.cabdirect.org/search.html?q=do%3A%22Review+of+Plant+Protection+Research%22)., 1975; Vol. 8 pp. 114-124; 19771936599
28. Kannan B. Narayanan, Natrajan Sakthivel,; Biological synthesis of metal nanoparticles by microbes; Advances in colloid and interface science;156; 2010; 1-13
29. Hirofumi ShounS and Tatsuo Tanimoto. Denitrification by the Fungus Fusarium oxysporum and Involvement of Cytochrome P-450 in the RespiratoryN itrite Reduction\* THE JOURNAL OF BIOLOGICAL CHEMISTRY 1993 by The American Society for Biochemistry and Molecular Biology, Inc ; Vol. 266, No. 17, Issue of June 15, pp. 11078-11062,1991
30. K.M. Moghaddam ; An introduction to microbial metal nanoparticle preparation method; the journal of young investigations; volume 19; issue 19 january 2010..
31. Duran, N.; Marcato, P.D.; Alves, O.L.; De Souza; G.I.H. & Esposito, E. (2005). Mechanistic aspects of biosynthesis of silver nanoparticles by several Fusarium oxysporum strains. Nanobiotechnology 3.; 8- 14.
32. Hedayati, M.T.; A.C. Pasqualotto, P.A. Warn, P. Bowyer, D.W. Denning (2007). "Aspergillus flavus: human pathogen, allergen, and mycotoxin producter". Microbiology (153): 1677–1692.[doi](http://en.wikipedia.org/wiki/Digital_object_identifier):[10.1099/mic.0.2007/007641-0](http://dx.doi.org/10.1099%2Fmic.0.2007%2F007641-0)
33. Williams, J. H., T. D. Phillips, P. E. Jolly, J. K. Stiles, C. M. Jolly, and D. Aggarwal. 2004. Human aflatoxicosis in developing countries: a review of toxicology, exposure, potential health consequences, and interventions. American Journal Of Clinical Nutrition 80 (5):1106-1122
34. Vigneshwaran, N.; Ashtaputre, N.M.; Varadarajan, P.V.; Nachane, N.P.; Paralikar, K.M. & Balasubramanya, R.H. (2007). Biological synthesis of silver nanoparticles using the fungus Aspergillus flavus. Materials letters. 61.; 1413- 1418.
35. Macdonald IDG; Orientation of cytochrome c adsorbed on a citrate-reduced silver chloride; 1996; Langmuir 12:706-713.
36. Kumar CV, McLendon GL (1997); Nanoencapsulation of cytochrome c and horseradish peroxidase at the galleries of zirconium phosphate; Chem Mater;9; 863-870
37. [Edward I. Campbell](http://link.springer.com/search?facet-author=%22Edward+I.+Campbell%22), [Shiela E. Unkles](http://link.springer.com/search?facet-author=%22Shiela+E.+Unkles%22),[Janet A. Macro](http://link.springer.com/search?facet-author=%22Janet+A.+Macro%22), [Cees van den Hondel](http://link.springer.com/search?facet-author=%22Cees+van+den+Hondel%22), [Roland Contreras](http://link.springer.com/search?facet-author=%22Roland+Contreras%22),[James R. Kinghorn](http://link.springer.com/search?facet-author=%22James+R.+Kinghorn%22). Improved transformation efficiency of Aspergillus niger using the homologous niaD gene for nitrate reductase . [Current Genetics](http://link.springer.com/journal/294), July 1989, Volume 16, [Issue 1](http://link.springer.com/journal/294/16/1/page/1), pp 53-56
38. L.R. Jaidev, G. Narasimha. Fungal mediated biosynthesis of silver nanoparticles, characterization and antimicrobial activity,; Colloids and Surfaces B: Biointerfaces 81 (2010) 430–433.
39. Spectral characterization and chemical modification of FMN-containing ascorbyl free-radical reductase from Pleurotus ostreatus; [S W Yu](http://www.ncbi.nlm.nih.gov/pubmed/?term=Yu%20SW%5Bauth%5D), [Y R Kim](http://www.ncbi.nlm.nih.gov/pubmed/?term=Kim%20YR%5Bauth%5D), and [S O Kang](http://www.ncbi.nlm.nih.gov/pubmed/?term=Kang%20SO%5Bauth%5D)’ Biochem J. 1999 August 1; 341(Pt 3): 755–763.
40. Devika R, Elumalai S, Manikandan E, Eswaramoorthy D (2012) Biosynthesis of Silver Nanoparticles Using the Fungus Pleurotus ostreatus and their Antibacterial Activity. 1:557 doi:10.4172/scientificreports.557
41. [A Gutiérrez](http://www.ncbi.nlm.nih.gov/pubmed/?term=Guti%26%23x000e9%3Brrez%20A%5Bauth%5D), [L Caramelo](http://www.ncbi.nlm.nih.gov/pubmed/?term=Caramelo%20L%5Bauth%5D), [A Prieto](http://www.ncbi.nlm.nih.gov/pubmed/?term=Prieto%20A%5Bauth%5D), [M J Martínez](http://www.ncbi.nlm.nih.gov/pubmed/?term=Mart%26%23x000ed%3Bnez%20MJ%5Bauth%5D), and [A T Martínez](http://www.ncbi.nlm.nih.gov/pubmed/?term=Mart%26%23x000ed%3Bnez%20AT%5Bauth%5D); Anisaldehyde production and aryl-alcohol oxidase and dehydrogenase activities in ligninolytic fungi of the genus Pleurotus; Appl Environ Microbiol. 1994 June; 60(6): 1783–1788
42. Shankar, S.S.; Rai, A.; Ahmad, A. & Sastry, M. (2004). Rapid synthesis of Au, Ag and bimetallic Au core- Ag shell nanoparticles using neem (Azadirachta indica) leaf broth. Journal of colloid and interface science. 275.; 496-502.
43. Husseiny I.M.; El-Aziz, A.M.; Badr, Y.; Mahmoud, A.M. (2007). Biosynthesis of gold nanoparticles using Pseudomonas aeruginosa, Spectrochimica Acta Part A, 67, 1003-1006
44. Koopmann GE, Batlle AM. [Biosynthesis of porphyrins in Rhodopseudomonas palustris--VI. The effect of metals, thiols and other reagents on the activity of uroporphyrinogen decarboxylase.](http://www.ncbi.nlm.nih.gov/pubmed/3595985) Int J Biochem. 1987;19(4):373-7
45. [Akopyan TN](http://www.ncbi.nlm.nih.gov/pubmed?term=Akopyan%20TN%5BAuthor%5D&cauthor=true&cauthor_uid=1055433), [Braunstein AE](http://www.ncbi.nlm.nih.gov/pubmed?term=Braunstein%20AE%5BAuthor%5D&cauthor=true&cauthor_uid=1055433), [Goryachenkova EV](http://www.ncbi.nlm.nih.gov/pubmed?term=Goryachenkova%20EV%5BAuthor%5D&cauthor=true&cauthor_uid=1055433). Beta-cyanoalanine synthase: purification and characterization., [Proc Natl Acad Sci U S A.](http://www.ncbi.nlm.nih.gov/pubmed/?term=cysteine+sulfide-lyase) 1975 Apr;72(4):1617-21
46. Bai, H.J.; Zhang, Z.M.; Guo, Y. & Yang, G.E. (2009). Biosynthesis of cadmium sulfide nanoparticles by photosynthetic bacteria Rhodopseudomonas palustris. Colloids and surfaces B: Biointerfaces 70.; 142-146.
47. Devendra Jain, Sumita Kachhawaha, Rohit Jain, Garima Srivastava, S L Kothari, Indian Journal of Experimental. Biology; vol 48, Nov 2010, pp 1152-1156.
48. Lengke MF, Ravel B, Fleet ME, Wanger G, Gordon RA, Southam G. [Mechanisms of gold bioaccumulation by filamentous cyanobacteria from gold(III)-chloride complex.](http://www.ncbi.nlm.nih.gov/pubmed/17120557) , Environ Sci Technol. 2006 Oct 15;40(20):6304-9
49. Lengke MF, Fleet ME, Southam G.Langmuir. [Morphology of gold nanoparticles synthesized by filamentous cyanobacteria from gold(I)-thiosulfate and gold(III)--chloride complexes.](http://www.ncbi.nlm.nih.gov/pubmed/16519482), 2006 Mar 14;22(6):2780-7.
50. Lengke MF, Fleet ME, SouthamG.Langmuir. [Synthesis of palladium nanoparticles by reaction of filamentous cyanobacterial biomass with a palladium(II) chloride complex.](http://www.ncbi.nlm.nih.gov/pubmed/17658865), 2007 Aug 14;23(17):8982-7
51. Lengke MF, Fleet ME, SouthamG. [Biosynthesis of silver nanoparticles by filamentous cyanobacteria from a silver(I) nitrate complex.](http://www.ncbi.nlm.nih.gov/pubmed/17309217) Langmuir. 2007 Feb 27;23(5):2694-9
52. Lengke MF, Fleet ME, Southam G. [Synthesis of platinum nanoparticles by reaction of filamentous cyanobacteria with platinum(IV)-chloride complex.](http://www.ncbi.nlm.nih.gov/pubmed/16893232) Langmuir. 2006 Aug 15;22(17):7318-23