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An Overview: Biological Organisms That Serves as Nanofactories for Metallic Nanoparticles Synthesis and Fungi Being the Most Appropriate

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Abstract

Nanotechnology implies to the manipulation, reduction and fabrication of materials at nano scale. Nanoparticles, exhibiting distinct morphological characteristics which is quite different from their bulk form. In recent years nanoparticles have been produced by industries for commercial application having many benefits. Biosynthesis of nanoparticles attracts many researchers and industries to explore microorganisms such as Bacteria, Fungi, Algae etc as the perfect biological system for the assembly of different nanoparticles. Fungi being the most suitable as mycosynthesis is not only ecofriendly but also makes the downstream processing for product recovery much easier.

Keywords: Bacteria; Algae; Fungi; Nanoparticles

Introduction

Different metallic nanoparticles are designed by the transformation of their bulk form in to nano scale [1], possessing unique properties with various uses in different fields such as biotechnology, nanotechnology, medicine, biochemistry and material engineering etc. [2]. Further many synthetic approaches being used for the fabrication of metallic nanocrystals, bio-based green methods have been established because it is not only environmental friendly but provides a clean and non-hazardous way for the fabrication of metallic nano sized particles. Bio-based amalgamation of nano particles using microorganisms as nanofactories is an innovative green technology that promises scientific benefits in future [3,4].

Microorganisms as bionanofactories

In recent years nanoparticles have been produced by industries for commercial application having many benefits. Biosynthesis of nanoparticles attracts many researchers and industries to explore microorganisms as the perfect biological system for the production of different nanoparticles. The metabolic activity of these microorganisms enables the extra cellular or intracellular synthesis of nanoparticles utilizing different mode of synthesis [5-8]. Microorganisms possess the capability to minimize the toxicity of metal ions through bio-reduction or by the aggregation of non-soluble complexes with metal ions to produce colloidal particles. In comparison, biologically synthesized nanomaterials are more definite in size than the chemically synthesized ones because of optimized growth of the crystal due to steady reaction kinetics which reduces the overall investment involved in nanoparticle synthesis. Not only reduction in the overall cost makes it less expensive process but also it is an eco- friendly method because it does not apply poisonous chemicals that are expensive and harmful for the environment as used in non-biological synthetic procedures that produces nanoparticles of poor morphology. Therefore nanoparticles of distinct morphology can be obtained through the optimization of culture conditions using biological organisms [9].

An account of organisms responsible for nanoparticle synthesis

Different metal nanoparticles, such as iron, silver, silica, selenium, gold, tellurium, platinum, quantum dots, lead, titanium, zirconium, magnetite, palladium, and silver –gold alloy can be biosynthesised by viruses, bacteria, fungi, plants and actinomycetes [10]. These organisms possess metal ion reduction capabilities thus making them suitable to be employed for synthesis of nanoparticles.

Bacteria in nanoparticle synthesis

Several bacterial species have been reported to produce metallic nanoparticles of different types. For example Bacteria like *Desulfuromonas acetoxidans*, *Shewanella* spp and *Magnetospirillum magnetotacticum* produces iron oxide nanoparticles [11]. In addition Copper and Cadmium sulfate nanoparticles were produce by photosynthetic bacteria of genus *Serratia* and *Rhodobacter sphaeroides* respectively [12,13] while *Escherichia coli* is reported to produce Cadmium nanocrystals [14].

Plants in nanoparticle synthesis

Not only bacteria but plants can also be used to produce nanoparticles of different types. For example from *Hordeum vulgare* (monocotyledonous) and *Rumex acetosa* (dicotyledonous) plants, iron oxide nanoparticles were produced [15]. In addition to that, *Diopyros kaki* leaf extract is known for the green production of platinum nano crystals [16], gold nanocrystals using *Gnidia glauca* flower extract [17], silver and gold nano crystals from Aloe Vera extract [18] and clove [19] have been reported.

Algae in nanoparticle synthesis

Chlorella vulgaris, unicellular green algae that possess the capability to produce crystalline metal nanoparticles at room temperature. The hydroxyl groups in tyrosine subunits or the carboxyl groups in

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S. No	Fungus name	Mechanism	Nanoparticles
1	*Fusarium oxysporum*	Extracellular	Pt [23]
		Extracellular	Ag [24,25,26]
		Extracellular	CdSe quantum dots [26]
		Extracellular	CdS [27]
		Extracellular	Magnetite [28]
		Extracellular	Si, Ti [29]
		Extracellular	Zirconia [30]
		Intracellular	Au [31]
		Extracellular	Au [32]
		Extracellular	BT [33]
		Intracellular	Zn [34]
2	*Verticillium sp.*	Intracellular	Au [35]
		Extracellular	Magnetite [28]
		Intracellular	Ag [36]
		Extracellular	Fe_3O_4 [28]
3	*Verticillium luteoalbum*	Intracellular	Au [37]
4	*Phoma sp.*	Intracellular	Ag [38]
5	*Phoma glomerata*	Extracellular	Ag [39]
6	*Colletotrichum sp.*	Extracellular	Au [40]
7	*Coriolus versicolor*	Extracellular	Ag [41]
8	*Cladosporium cladosporioides*	Extracellular	Ag [42]
9	*Usnea longissima*	Extracellular	Usnic acid [42]
10	*Trichothecium sp.*	Extra/Intra	Au [43]
11	*Trichoderma asperellum*	Extracellular	Ag [44]
12	*Aspergillus fumigates*	Extracellular	Ag [45]
		Extracellular	ZnO [46]
13	*Fusarium semitectum*	Extracellular	Ag [47]
		Intracellular	Au [48]
14	*Aspergillus flavus*	Intracellular	Ag [49]
		Extracellular	TiO_2 [50]
15	*Aspergillus niger*	Extracellular	Ag [51]
		Extracellular	Au [52]
		Intracellular	Au [52]
16	*Fusarium acuminatum*	Extracellular	Ag [53]
17	*Penicillium sp.*	Extracellular	Ag [54]
18	*Helminthosporum solani*	Extracellular	Au [55]
19	*Fusarium solani*	Extracellular	Ag [56]
20	*Aspergillus oryzae*	Extracellular	$FeCl_3$ [57]
21	*Aspergillus tubingensis*	Extracellular	$Ca_3P_2O^8$ [58]
22	*Rhizopus oryzae*	Cell surface	Au [59]
23	*Rhizopus stolonifer*	Cell surface	Au [60]
		Extracellular	Ag [61]
24	*Aureobasidium pullulans*	Intracellular	Au [31]
25	*Neurospora crassa*	Extracellular	Au [27]
26	*Penicillium brevicompactum*	Extracellular	Au [62]
27	*Cylindrocladium floridanu*	Extracellular	Au [63]
28	*Phanerochaete chrysosporium*	Extracellular	Au [64]
29	*Volvariella volvacea*	Extracellular	Au [65]
30	*Sclerotium rolfsii*	Extracellular	Au [63]
31	*Coriolis versicolor*	Extracellular	Au [66]
		Intracellular	Au [66]
		Extracellular	Ag [41]
		Intracellular	Au [46]
32	*Candida albicans*	Intracellular	Au [67]
33	*Pleurotus sajor caju*	Extracellular	Ag [49]
34	*Penicillium fellutanum*	Extracellular	Ag [68]
35	*Penicillium strain J3*	Extracellular	Ag [69]
36	*Trichoderma viride*	Intracellular	Ag [70,71]
		Extracellular	
37	*Amylomyces rouxii KSU-09*	Extracellular	Ag [72]
38	*Aspergillus clavitus*	Extracellular	Ag [73]
39	*Aspergillus terreus CZR-1*	Extracellular	Ag [74]

Table 1: List of different metal nanoparticles produced by fungi.

glutamine/aspartic subunits of the proteins present in the extract are accountable for silver ion reduction and also aids in controlling the definite size of nanosilver crystals [20].

Fungi in nanoparticle synthesis

From a total of 1.5 million species of fungi found on Earth about seventy thousands species have been documented. According to a recent study it was estimated that nearly 5.1 million fungal species are found on Earth by the use of high-through put sequencing methods [21]. Selecting Fungi for mycofabrication purposes is the most pertinent choice because of its high metal ion tolerance and bioaccumulation capabilities [22]. Intra or extracellular mycosynthesis of a number of different metallic nanoparticles have been enlisted in Table 1 [23-74].

Why fungi being the most appropriate?

Using fungal biomass or biomass extracts, for the production of nanoparticles is more advantageous compared with other biological methods because fungi, being abundant in nature can be easily isolated by plating, serial dilutions and hyphal extraction. Culturing/sub-culturing requires simple media nutrients and since they are totipotent therefore spores or hyphae can be used to grow fungus to obtain pure isolate after sub culturing [75,76]. Besides have the potential to be scaled up for large-scale synthesis by producing large amounts of extracellular enzymes which catalysis the heavy metal ions to produce the respective metallic nanoparticle of definite size and shape. Myco-synthesis offers simple downstream processing for product recovery with easy biomass handling [10], thus making the whole process environmental friendly and cost effective.

Conclusion

Among different biological organisms, Fungi serve as a prime candidate for the production of different nanoparticles because of its high tolerance towards metal ions with reduction capabilities. Above all makes the downstream processing for product recovery easy.

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