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Role of Bacteria in Nanoparticle(S) Synthesis and Their Applications

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Abstract

Nanoparticles are small molecules with size ranging between 1-100nm. Basis of their classification is their properties shapes and size. These find usage in wide range of industries from agricultural, biomedical, environmental and food. There are numerous ways of producing these nanoparticles using chemicals and biological means. Use of various micro-organisms (biological process) is highly effective in producing high quality, toxin free and cost effective nanoparticles. In this context, present article concerns with association of bacteria with nanoparticles. Here "Green Synthesis" of nanoparticles through the use of different bacteria is discussed. Contrasting nanoparticles such as cadmium, silver, copper, zinc, gold, platinum, magnetic, tellurium etc. can be synthesized through various bacterial species like *Bacillus cereus, Pseudomonas antarctica, Shewanella algae, Deinococcus radiodurans, Xanthomonas oryzae, Alcaligenes faecalis, Neurospora crassa, Rhodopseudomonas capsulata, Arthrobacter kerguelensis* etc.

Nanoparticles and bacteria are used in association for different applications an over view of which is presented in the articles. Also, the association among the two for the drug delivery to the target site has been looked upon.

Keywords: Nanoparticles; Green Synthesis; Nanoparticles-Bacteria Drug Delivery Vehicle

Introduction

Nanoparticles are of size 1-100nm and can be made from carbon, metal oxides or other organic matter [1]. All the nanoparticles have ability to show distinguished biological, physical and chemical properties at Nano-scale. Nanoparticles exhibit properties like increased reactivity and stability in a chemical processes, enhanced mechanical strength etc. [2]. These have gathered much attention because of different and interesting properties, applications and advantages over their bulk counterparts. Nanoparticles are of different shape and sizes like zero dimensional e.g. nanodots, one dimensional e.g. graphene, two dimensional e.g. carbon nanotubes, three dimensional e.g. gold nanoparticles. They can be hollow core, cylindrical, spherical, conical, tubular, spiral, flat or even irregular in shape [3]. They also differ in structure which can range from amorphous to crystalline with one or more crystals [4,5]. Nanoparticles have biomedical applications and thus eco-friendly and nontoxic methods should be used for their synthesis. The preferable way to synthesize nanoparticles is by using micro-organisms, which is the most superior method as well as cost effective [6]. Use of micro-organisms is energy efficient and environmental friendly way to produce nanoparticles which can be used to perform functions like drug carrier for target delivery, gene therapy, DNA analysis, biosensor, MRI [7].

Thus it can be said that different micro-organisms play a vast role in production of industrially important nanoparticles. Taking this into consideration, the present article includes an overview of nanoparticles, used of various micro-organisms (especially bacteria) in production of different kind of nano particles and their applications.

Sources of Nanoparticles

Sources of Nanoparticles are Mainly Classified in 3 Categories

- **Incidental Nanoparticles:** These are incidentally produced materials, which are actually the by-product of different industrial processes. Like Nanoparticles formation from engine exhaust, welding fume, or even some of natural processes may include like forest fire, photochemical reaction, ocean evaporation, volcanic eruptions etc [8]. These naturally originating events can produce high amount of nanoparticles. Likewise some other human activities also lead to nanoparticle synthesis like charcoal burning, dust storm and cosmic dust etc [9].

- **Engineered Nanoparticles:** These are self-designed type of nanoparticles which are engineered to have certain desirable qualities and applications. Many of the anthropogenic activities may be conclude for synthesis of such nanoparticles such as diesel or engine exhaust burning [10], building demolition and cigarette smoke, nanoparticles from biomedical and healthcare. Thus these contain synthetic nanoparticles, which are the new genre of nanoparticles which can completely show suspicious environmental and human health effects.

- **Natural Nanoparticles:** These are very easily found and can be synthesized from bodies of organisms, insects, plants, animals and even human beings [11]. Unlike incidental and engineered nanoparticles, natural nanoparticles are present in living organisms

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Table 1: Classification of nanoparticles.

Sr. No.	Type of Nps	Sub Type of Nps	Example
1	Carbon	Fullerenes	TiO_2
		Graphene	
		Carbon Nanotubes	
		Carbon Nanofibres	
		Carbon Black	
2	Organic	Dendrimers	CdSe
		Liposomes	
		Micelles	
3	Inorganic	Metal Based	Gold, Silver
		Metal Oxide Based	ZnO, TiO_2
4	Composite	Simple Hybrid	SiO_2
		Core or Shell Structured	
		Multifunctional Quantam Dots	

ranging from microorganisms like bacterial, algae, virus to complex organisms like plants, insects, animals, birds and humans. This knowledge of presence of nanoparticles in microorganisms can be important because of their further use in biomedical applications [12,13].

Classification of Nanoparticles

There are 4 material based categories in which nanoparticles and nano sized materials can be organised (Table 1).

- **Carbon based Nanoparticles:** These types of nanoparticles are mainly formed of carbon. Examples of its morphology are hollow tubes, ellipsoids etc. These could be further classified into Carbon Nano Tubes (CNT), carbon black, fullerenes, graphene, carbon nanofibers and activated carbon in nano size [14].

- **Organic Nanoparticles:** These nanoparticles unlike carbon based nanoparticles are made up of organic matter. Non covalent interactions (being weak) are helpful for self-assembly and design of molecule in transformation of organic nanoparticles into desired structure such as dendrimers, micelles, liposomes, ferritin etc [15]. These nanoparticles are mostly biodegradable and non-toxic, among which some form hollow core (such as micelles and liposomes) also known as nanocapsules and they become sensitive to electromagnetic and thermal radiation such as heat and light. This characteristic makes such nanoparticles as ideal choice for drug delivery mechanism [4,16].

- **Inorganic Nanoparticles:** Inorganic nanoparticles are highly stable compared to their organic counterparts. They are biocompatible, non-toxic and hydrophilic materials. These are the metal and metal oxide based nanoparticles. These nanoparticles have certain types into which they can be synthesized, out of which metals may include Au, Ag nanoparticles [17], similarly metal oxides may include TiO_2, ZnO and even some semiconductors like silicon and ceramics [18].

- **Composite Nanoparticles:** These are nanoparticle of composite structures, including core shell structure, onion like structure and gladiate composition. These nanoparticles are multiphased with one of their phase on nanoscale dimension which can be helpful in combining one nanoparticle with other such as hybrid nanofibres or even complicated structures such as metal organic frameworks. These type of composites may be formed of any combinations be it metal-based, organic-based or carbon-based with any form of metal, ceramic, or polymer bulk materials [12,19].

Bacterial Association of Nanoparticles

Production of Nanoparticles

Green nanotechnology makes use of various biological entities for nano-particles production. Use of bacteria for nanoparticle biosynthesis is popular among the scientific community and is gaining importance for because of various beneifits it offers. Various bacteria have been employed for production of nano-particles (Table 2). One of the important factors of green synthesis is that microbial emissary has a tendency of acting as a template for synthesizing as well as organizing the nanoparticles into precise structure. Bacteria in particular are capable of immobilization and mobilization of diffrerent metals and in cases, it can reduce metal ions and precipitate metals at a nanometer scale. Optimising the process of production is easied with used of bacteri which can lead to synthesis of nanoparticles with the desired size and morphology.

Bacteria have ability to reduce heavy metal ions which makes them desirable candidates for synthesis of nanoparticle. It was found in a study that *P. stutzeri* and *P. aeruginosa* are able to survive and grow in high metal ion concentration [20,21]. Previous studies have reported bacteria like *Thiobacillus thiooxidans, Thiobacillus ferrooxidans, and Sulfolobus acidocaldarius* are capable of reducing ferric ion to its ferrous state when sulfur is used as an energy source. Other bacteria were also found to be beneficial such as enzymatic reduction of Tc (VII) using *Geobacter metallireducens* and *Shewanella putrefaciens* cells in their resting phase, Escherichia coli K12 utilized for tellurium (Te) formation [22], and used of by *Rhodospirillum rubrum, Desulfovibriode sulfuricans, Enterobacter* cloacae for reduction of

Table 2: Bacteria utilized for production of nanoparticles.

Sr. No.	Bacteria Used	Nanoparticles	Size(Nm)	References
1	*Bacillus cereus*	Silver	20-40	[26]
2	*Kocuriaflava*	Copper	05-30	[27]
3	*Bacillussubtilis*	Gold	20-25	[28]
4	*Shewanellaloihica PV-4*	Platinum	02-07	[29]
5	*Sinomonasmesophila MPKL 2*	Silver	04-50	[30]
6	*Xanthomonasoryzae*	Silver	14-86	[31]
7	*B.subtilis*	TiO_2, ZnO	66-67	[32]
8	*E.coli*	CdO	22-25	[33]
9	*Rhodopseudomonas capsulata*	Gold	10-20	[34]
10	*Shewanella algae*	Platinum	~5	[35]
11	*Deinococcus radiodurans*	Gold	~43.75	[36]
12	*Bacillus cecembensis*	Silver	06-13	[37]
13	*Pseudomonasantarctica*	Silver	06-13	[37]
14	*Magnetotactic*	Magnetic	-	[38]
15	*Alcaligenesfaecalis*	Silver	30-50	[39]
16	*Ochrobactrum* sp. MPV	Tellurium	02-05	[40]

Table 3: Applications of bacterially synthesized nanoparticles.

Sr. No.	Bacteria Used	Nanoparticles	Applications	References
1	*Bacillus cereus*	Silver	Antibacterial Activity	[26]
2	*Alcaligenes faecalis*	Silver	Antimicrobial and antibiofilm activty	[38]
3	*Pseudomonas aeruginosa*	Cadmium	Removal of Cadmium Pollutant	[43]
4	*Shewanella loihica PV-4*	Palladium and Platinum	Degradation of Methyl Orange Dye	[29]
5	*Ochrobactrum* sp. MPV	Tellurium	Reduction of Toxic compounds	[39]
6	*Bacillussubtilis*	Gold	Degradation of Methylene Blue	[28]
7	*Klebsiellapneumonia*	Silver	Antimicrobial	[44]
8	*Nostoc* sp. strain HKAR-2	Silver	Antimicrobial effect on *Ralstonia solanacearum, Xanthomonas campestris, Aspergillus niger,*	[45]
9	*Halomonas maura*	MR	Antiangiogenic, Anti-inflammatory, Anti- viral activities	[46]
10	*Anabaena dolium*	Silver	Antimicrobial effect on *K.pneumonia and S.aureus*	[47]
11	*Brevibacterium frigoritolerans*	Silver	Antimicrobial effect on *Vibrio parahaemolyticus, Bacillus anthracis, Salmonella enterica*.	[48]

selenite to selenium [23]. Mullen et al. [24] studied the capability of *E. coli*, *Bacillus subtilis, P. aeruginosaand Bacillus cereusin* removing La^{3+},Cd^{2+}, Ag^{+} and Cu^{2+} from solution. Some of the bacteria even synthesize inorganic materials, example being magnetotactic bacteria, which results in synthesis of intracellular magnetite nanoparticles [25].

In a study *E. coli* was used for production of DH5α gold nano particles using $AuCl_4$ ions aqueous bio-reduction with bacterium. A study reported, platinum group metals undergo reductive deposition carrying out heterogenous reaction for synthesis of platinum nanoparticles on bacterium *Shewanella algae* [41]. It is an environment friendly method termed as "green chemistry" for production of nanoparticles. Certain thermophilic bacteria are utilized in a great extent for extracellular production of the metal nanoparticles like gold or silver. *Thermophillus* microorganisms as *Geobacillus stearothermophilus* have shown the properties of formation nanoparticles [42]. *Geobacillus* sp. was cultivated for obtaining a wet biomass, and then was exposed to metal salts. The complete reaction process led to production of nanoparticles. Nanoparticles produced by this process accompanied with presence of capping proteins which suggests that nanoparticles formed are of highly stable in nature. Also this technique leads to production of toxin free nanoparticles and highly recommended for large scale synthesis [42].

Applications of Nanoparticles

The applications of nanoparticle are as diverse as its characteristics. Today, nanoparticles are used in different fields as biomedical, agriculture, environment and industires. Though here we are concerned with different applications of nanoparticles in association with bacteria. The interaction of various bacteria and nanoparticles have been used to perform various fnctions. Many studies have shown that depending upon their characteristics various nanoparticles can penetrate the outer membranes of bacterial cells and form an association with the latter. This association enhances the characteristics of both which can now be used for various applications. An overview of applications of bacteria syntesized nanoparticles is mentioned in the Table 3.

Association of Bacteria with Nanoparticles for Drug Delivery

Due to the characteristics of nanoparticles they are considered as ideal molecules for delivery of many drugs to their desired destination. Many bacteria help nanoparticles in this process. The nanoparticles become leaped on the surface of bacterium and this combined form can be used as applications for gaining direct knowledge about electrochemistry of proteins. Nanoparticles in association with bacteria are being employed for constructing bacteria-nanoparticle vehicles. Patinum (nano- Pt) and gold (nano-Au) nanoparticles in association with *Listeria monocytogenes Salmonella enteritidis* and is one such bacteria-nanoparticle vehicles which can be used for drug delivery. Series of experiments led to conclusion that nano-Au and nano-Pt can disrupt the cell wall and membrane of the *Salmonella enteritidis* and *Listeria monocytogenes* and gets combined with the DNA material thus making it a desirable vehicle for drug transfer [49].

Likewise, *Halomonas maura* (ATCC 700995) is another bacterium species which helps in formation of Mauran (MR) or Chitosan (CH) nanoparticles [46]. These are highly halophile bacteria which can produce highly sulphated Exo-Polysaccharides (EPS) residues. *Halomonas Maura* bacterium is grown and cultivated along with the EPS. After carrying out of the complete Reaction Process (MR) based nanoparticles were formed. Various techniques like FTIR, XRD, TEM & SEM confirms the presence of these MR nanoparticles. These produced nanoparticles also bear the drug delivery mechanism. These records depict that these MR nanoparticles have advantage of sustained delivery of drug for period of about 10-12 days. Also as these nanoparticles have tendency for encapsulated anticancer drug; they have a high potential of fighting against tumorous cells. Along with the mechanism of encapsulating anticancer drugs, these nanoparticles bear property of sustained and controlled drug release, under optimum conditions like high acidic pH, making them favourable for cancer chemotherapy [46].

Conclusion

There is an immense scope of using bacteria for production of nanoparticles. As various nanoparticles find used in many different industries, it is ideal to find cheaper and effective ways for their production. Conventional used of various chemicals nanoparticles productions is costly as well as accompanied with many toxic by-products. Using micro-organism especially bacteria can be the possible solution to this problem. Not only the production process is cost effective and toxin free but also the process can be optimised leading to the production of nanoparticles with the desired characteristics. Nanoparticles produced using bacteria are used for various applications and an association among them can be helpful in drug delivery. Further studies need to be conducted to make this association beneficial for mankind. For instance, studies suggest that many nanoparticles can disrupt outer walls of bacterial to integrate with the genetic material of the host cell; this mode of interaction can be exploited to kill pathogens.

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Declaration of Competing Interest

Authors declare that they have no conflict of interest amongst themselves or with parental institute.

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