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Effect of Nanoparticles on Biodiversity of Soil and Water Microorganism Community

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Abstract

Nanostructured materials are in the frontline of the present scientific research because of their multifunctional properties that leads their applications from optics to electronic, from mechanical engineering to medical science and technology. However increased levels of nanomaterials in the environment drastically affect the lifestyle activity of the microorganism of the environment. This also changes the biodiversity of the system. This mini review discusses about effect of nanoparticles on the Biodiversity of Soil and Water Microorganism Community as reported by the researchers. Also the mechanism of nanoparticle-microorganism interaction and functionality has been discussed.

Keywords: Nanomaterials; Nano-medicine; Microorganism; Environment; Biodiversity

Introduction

Nanomaterials are in the forefront of recent research community due to their unique properties compared to their bulk counterpart due to the well-known quantum confinement effect [1-3]. Metal oxide (MO) nanostructured materials are very widely investigated due to their potential applications in electronics, opto-electronics, spintronic and memory devices [4-6]. Moreover, these are also being used in solar-cell, photovoltaics, piezo-electronic devices [7,8]. Amongst several metal oxides, zinc oxide, and titanium oxide are very commonly used in sunscreens and cosmetics [9-13]. With the increasing production and use of nanomaterials, their inevitable release to the environment increases. Most of the commonly used nanomaterials are not bio-degradable and thus remain in the environment (in soil, water and air). This leads to the change the pH, toxicity, salinity, natural organic and bio content of soil and water. Thus the flora and fauna community of the environment is directly affected by the release of nanoparticles (NPs) into the environment. Thus the eco-toxic effect of NPs is to be considered very seriously. It has been reported that Ag, Au and TiO_2 NPs can directly affect the progeny and reproduction of roundworms (nematodes) and water fleas (daphnids) [14]. This is because the NPs when come into the cell wall of the micro-organism, they penetrate the cell and changes the conductivity of the cytoplasm of the cells and thereby affect the normal functioning of the cell. Here, in this mini-review, I shall discuss about the effect of nanoparticles on biodiversity of soil and water microorganism community.

Release of Nanoparticles into the Environment

There are several ways through which NPs are released into the environment. Metal oxide nanoparticles like ZnO and TiO_2 are used widely in several sunscreens, facial masking, cosmetics and coatings in glass [15-17]. They are directly released into the environment after use. It has been reported that both ZnO and TiO_2 show anti-bacterial activity [18-20]. Thus they directly affect the micro-organism of water, soil and water when come into direct contact. Several nanomaterials wastes are also produced during the production of several products like carbon NPs in tonnage, SiO_2, Ag and Au NPs in glass industries. These are directly mixed to the river water and affect the activity of micro-organisms of water. It has been observed experimentally that most of the NPs are retained in sewage sludges while a very small amount are found in surface water bodies [21].

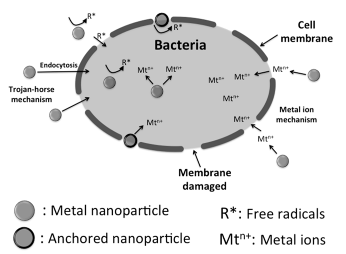

Figure 1: Mechanisms associated with the antimicrobial behaviour of metal nanoparticles: (1) "Trojan-horse effect" due to endocytosis processes; (2) attachment to the membrane surface; (3) catalyzed radical formation; and (4) release of metal ions.

Existence of NPs in the Environment and their Transformations

Most of the NPs commonly used are all inorganic and non-bio-degradable. So, once they are released into the environment they affect the environmental conditions by sedimentation, agglomeration, adsorption by the microorganisms, surface adhesion, dissolution and transformation. The degree of degradation depends on the type of the NPs and their particle size. Electrostatic interactions lead to the agglomeration process of NPs in the environment. The rate of agglomeration, sedimentation and adsorption depends on the concentration of NPs, surface area of interaction, surrounding medium. Some nanomaterials also get transformed (by the process of oxidation or reduction) during their persistence in the environment. Sometimes, in presence of other elements of the environment structural, mechanical and charge transfer characteristics of the nanomaterials also get changed.

Mechanism of NPs-Microorganism Interaction and Impact on Biodiversity

Nanoparticles dissolved in water and soil is directly absorbed by several microorganisms and plants. Once the NPs come into the cell wall of the microorganism, they immediately penetrate it if the size of the NPs is ~50 nm [22]. Once the NPs penetrate the cell wall, it affects the conductivity of the cytoplasm of the cell. The size of the NPs plays most important role in this surface interaction process. As the size reduces, more number of atoms is exposed to the surface hence more atoms can interact with the bacterial cells. The schematic of the process is illustrated in Figure 1. The antimicrobial effect of ZnO NPs on *S. aureus, S. marcescens, Neisseria. gonorrohea, P. mirabilis,* Klebsiella, *Streptococcus mutans, Vibrio cholerae, E. coli, C. freundii* and on fungi like *A. nidulans, A. flavus. A spergillus niger* and *R. stolonifer* is reported in the literature by the researchers [23-28]. Silver NPs are found to be very toxic to several bacteria. Hence the use of Ag-NPs is growing day-by-day in various medicinal applications [29]. However there are some bacteria which are silver-resists. They precipitate the silver in metal form or some insoluble form. It is also experimentally demonstrated that several microorganisms like water fleas, earthworms, fishes absorbs nanoparticles during their food intake and a low level of accumulation is observed in several organs [21]. Sometimes the NPs enter into the blood and muscles of the organism. This affects the organs to work in normal way. Thus the function of the cell is disrupted. Several methods such as disk diffusion, broth dilution, agar dilution and the microtiter plate-based method have been reported in the literature to investigate the antibacterial activity of NPs *in vitro* [30-32]. However, there are some other indirect methods also like bacterial metabolism-induced change in conductivity, and flow cytometry [33,34]. The basic mechanism of antibacterial activity of NPs is the toxicity of the materials. But the exact mechanism of toxicity and antibacterial activity is yet not well established. There are several mechanism reported by the researcher behind the antibacterial activity of NPs. Zhang et al. [35] had shown that the antibacterial activity of ZnO NPs depend on the particle size and particle concentration. It was also found that the encapsulation of the NPs by Polyethylene Glycol (PEG) or Polyvinylpyrolidone (PVP) does not affect the antibacterial activity of ZnO NPs significantly. They showed that the antibacterial activity was originated due to destruction of cell membrane of bacteria upon direct interaction with the NPs. Other causes may be Zn^{2+} ion liberation and reactive oxygen species. These antibacterial/microbial effects of NPs lead a potential problem to the biodiversity. Researchers are trying to synthesise NPs in green route and enzyme route so that the synthesized NPs are less hazardous [36,37]. So these NPs have weaker effect on the soil-water-air microbes. However, still it is a big challenge to save the soil, water microorganism and to preserve the biodiversity.

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