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Review article

Influence of environmental factors on nanotoxicity and knowledge gaps thereof

Chaoxiu Ren, Xiangang Hu *, Qixing Zhou *

Key Laboratory of Pollution Processes and Environmental Criteria (Ministry of Education), Tianjin Key Laboratory of Environmental Remediation and Pollution Control, College of Environmental Science and Engineering, Nankai University, Tianjin 300071, China

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ABSTRACT

Nanomaterials develop rapidly and are applied in various fields. Generally, these nanomaterials are released into the environment and lead to potential nanotoxicity and environmental risks. Importantly, the environmental behaviors and properties of nanomaterials will inevitably be influenced by environmental factors. As a result, biological responses of the nanomaterials under the action of environmental factors are largely different from those of pristine nanomaterials. Therefore, this review discussed the influence of environmental factors (e.g., light irradiation, natural organic matter, ionic strength, coexisting contaminants, temperature, biomedium and chemical surface modifications) on nanotoxicity and the relevant knowledge gaps, and then explored the mechanisms thereof. Environmental factors affected nanotoxicity by regulating their physicochemical features, changing physiological damage, oxidative stress, and biomolecular responses caused by nanomaterials. In addition, the synergic effects of environmental factors and the dominant factors in natural environment should be taken into consideration when nanotoxicity is discussed. At the end of the review, the global perspectives of nanotoxicity with the influence of environmental factors are proposed.

Contents

1. Introduction

Nanomaterials are engineered structures with at least one dimension of 100 nanometers (nm) or less. Nanomaterials develop rapidly and are used extensively in applications such as phototherapy, early diagnosis of cancer, drug carriers, tissue engineering, electronic components, cosmetics, food additives, water treatment and soil remediation (Kotagiri et al., 2015; Chen et al., 2007; Shehada et al., 2015; Cabral et al., 2015; Herle et al., 2004; Li et al., 2014a). Finally, these nanomaterials or products containing nanomaterials will likely be released into the air, water, and soil in the natural environment (Maynard et al., 2006). Thus, their safety with regard to the environment and organisms has attracted considerable attention (Akhavan and Ghaderi, 2010; Setyawati et al., 2015). Nanomaterial properties differ substantially from those bulk

* Corresponding authors.
E-mail addresses: huxiangang@nankai.edu.cn (X. Hu), zhouqx@nankai.edu.cn (Q. Zhou).

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materials of the same compositions, exhibiting high surface activity, optical sensitivity and biological availability. Compared with the positive applications, possible undesirable results of nanomaterials are harmful interactions with biological systems and the environment (Nel et al., 2006; Menard et al., 2011). Furthermore, the exposure of nanoparticles (NPs) can trigger DNA damages (Akhavan et al., 2015; Akhavan et al., 2016b). The suspension, deposition behavior and toxicity of nanoparticles (NPs) have been extensively studied in laboratory environments (Wang et al., 2015a; Xia et al., 2013; Bai et al., 2010). However, once NPs are released into the natural environment, environmental factors, such as light irradiation, nature organic matter (NOM), ionic strength, coexisting contaminants, temperature biomedium and chemical surface modifications, will affect the physicochemical properties and toxicity of NPs. In addition to pristine nanomaterials, environmentally transformed nanomaterials deserve much attention to guarantee their environmental safety.

Some studies have investigated the interaction between environmental factors and the environmental behavior, fate and toxicity of NPs. Transformed nanomaterials exhibit different and even opposite biological responses compared with pristine nanomaterials. At present, there are still some disputes in nanotoxicological research. For example, a previous work showed that there were no obvious toxicity of carbon nanotubes (CNTs) to rats (Lee et al., 2011), while an opposite result was presented in another report (Mitchell et al., 2009). There are some arguments for the toxicity of graphene as well. Luan et al. indicated that graphene induced toxicity to cells, but Hu et al. found that graphene induced little toxicity (Luan et al., 2015; Hu et al., 2015). It was because the environmental factors changed the physicochemical property of NPs. These reports with different results tell us: although factors that modify nanoparticle behavior and interaction with biota are well known, it is still not easily to predict outcomes in complex exposure scenarios. Therefore, much work needs be done to fill the relevant knowledge gaps. For example, once exposed to the natural environment, the physicochemical properties and toxicity of NPs will be regulated by multiple environmental factors rather than just one. The combined effects of environmental factors should be taken into consideration when nanotoxicity is discussed.

This review aims to discuss the influence of environmental factors (e.g., light irradiation, NOM, ionic strength, coexisting contaminants, temperature, biomedium and chemical surface modifications) on nanotoxicity, as summarized in Fig. 1. The factors, such as light irradiation, NOM, ionic strength, coexisting contaminants, temperature, biomedium and chemical surface modifications, are ubiquitous around NPs in natural environment. Furthermore, these factors will affect the physicochemical features, fate and toxicity of NPs. Furthermore, the reason why is still not easily to predict the effects of NPs on organisms in complex exposure scenarios will be discussed. And then the mechanisms of nanotoxicity regulated by environmental factors are explored. For instance, environmental factors influence nanotoxicity by regulating agglomeration and physicochemical features of NPs or by changing physiological damage, oxidative stress, or biomolecular responses caused by NPs. In addition, the synergic effects of environmental factors on NPs and the dominant factors in nature are explored. The knowledge gaps and challenges are illustrated at the end of each individual section. Finally, the global perspectives of nanotoxicity with the influence of environmental factors are proposed.

2. Influence of environmental factors on nanotoxicity

2.1. Influence of light irradiation on nanotoxicity

When nanomaterials are released into the natural environment, they will be inevitably exposed to light irradiation from the sun or artificial lighting. Many nanomaterials are innately nontoxic or less toxic to organisms. However, when they are under light irradiation, the toxicity will be enhanced (Li et al., 2012; Dasari et al., 2013; Li et al., 2014c). In contrast, light irradiation also reduced the toxicity of nanomaterials through passivating action (Shi et al., 2013; Shi et al., 2012b).

Properties of NPs can be changed by light irradiation. Some nanomaterials are photoactive (e.g., fullerenes, carbon nanotubes and

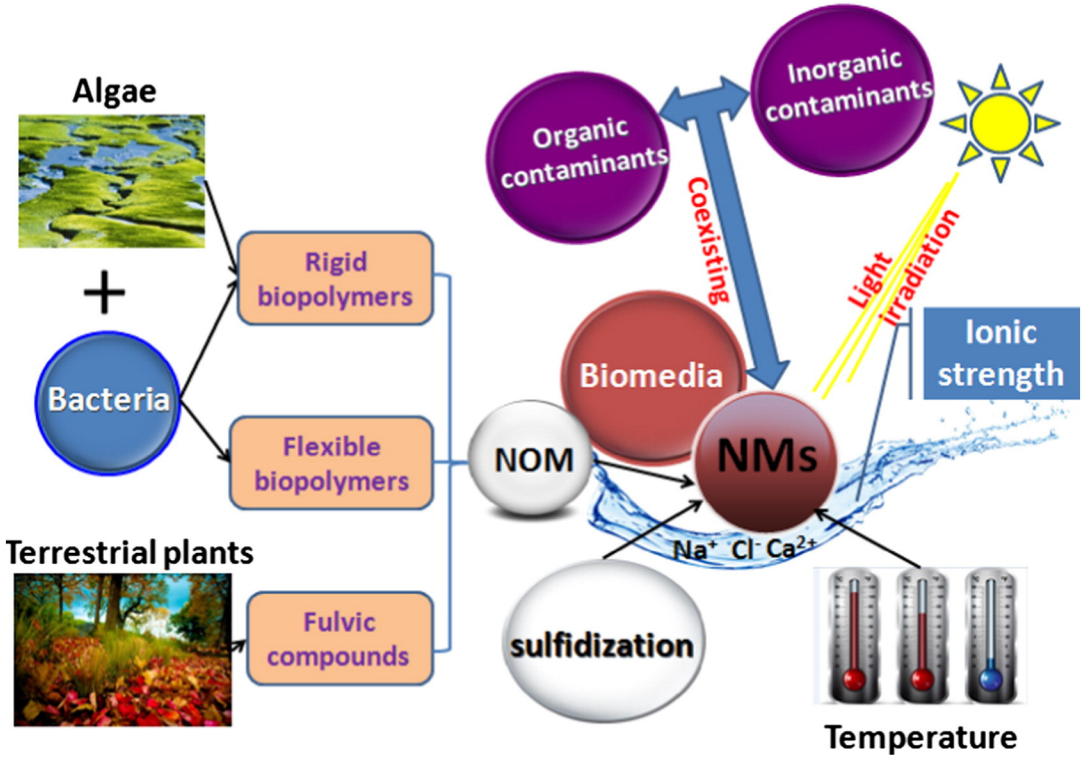

Fig. 1. Environmental factors influencing nanotoxicity. NOM (natural organic matters) mainly include rigid biopolymers, flexible biopolymers and fulvic compounds; NMs, nanomaterials.

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