Environmental Research 151 (2016) 233–243

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Review article

Transport phenomena of nanoparticles in plants and animals/humans

Naser A. Anjum[a,*,1], Miguel Angel Merlos Rodrigo[b,c,1], Amitava Moulick[b,c,1], Zbynek Heger[b,c,1], Pavel Kopel[b,c], Ondřej Zítka[b,c,**], Vojtech Adam[b,c], Alexander S. Lukatkin[d], Armando C. Duarte[a], Eduarda Pereira[a], Rene Kizek[b,c,**]

[a] CESAM-Centre for Environmental and Marine Studies & Department of Chemistry, University of Aveiro, 3810-193 Aveiro, Portugal
[b] Department of Chemistry and Biochemistry, Laboratory of Metallomics and Nanotechnologies, Mendel University in Brno, Zemedelska 1, CZ-613 00 Brno, Czech Republic
[c] Central European Institute of Technology, Brno University of Technology, Technicka 3058/10, CZ-616 00 Brno, Czech Republic
[d] Department of Botany, Physiology and Ecology of Plants, N.P. Ogarev Mordovia State University, Bolshevistskaja Str., 68, Saransk 430005, Russia

ARTICLE INFO

Article history:
Received 26 April 2016
Received in revised form
12 July 2016
Accepted 13 July 2016

Keywords:
Nanoparticles
Transport phenomena
Plant
Animal
Human

ABSTRACT

The interaction of a plethora nanoparticles with major biota such as plants and animals/humans has been the subject of various multidisciplinary studies with special emphasis on toxicity aspects. However, reports are meager on the transport phenomena of nanoparticles in the plant-animal/human system. Since plants and animals/humans are closely linked *via* food chain, discussion is imperative on the main processes and mechanisms underlying the transport phenomena of nanoparticles in the plant-animal/human system, which is the main objective of this paper. Based on the literature appraised herein, it is recommended to perform an exhaustive exploration of so far least explored aspects such as reproducibility, predictability, and compliance risks of nanoparticles, and insights into underlying mechanisms in context with their transport phenomenon in the plant-animal/human system. The outcomes of the suggested studies can provide important clues for fetching significant benefits of rapidly expanding nanotechnology to the plant-animal/human health-improvements and protection as well.

Contents

* Corresponding author.
** Corresponding authors at: CESAM-Centre for Environmental and Marine Studies & Department of Chemistry, University of Aveiro, 3810-193 Aveiro, Portugal (NAA); Department of Chemistry and Biochemistry, Laboratory of Metallomics and Nanotechnologies, Mendel University in Brno, Zemedelska 1, CZ-613 00 Brno, Czech Republic (OZ and RK).
E-mail addresses: anjum@ua.pt (N.A. Anjum), zitkao@seznam.cz (O. Zítka), kizek@sci.muni.cz (R. Kizek).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.envres.2016.07.018
0013-9351/

1. Introduction

Rapid production and interdisciplinary applications of varied engineered nanoparticles (particulate matter with at least one dimension that is less than 100 nm) in everyday life are constantly increasing worldwide (Fig. 1). Varied nanoparticles may be released into different environmental compartments, such as soil, either during production processes, transport or by direct or indirect disposal of consumer products upon use. Therefore, organisms and especially those that strongly interact with their immediate environments, such as plants, microorganisms and edaphon have a greater chance to be exposed to and impacted with nanoparticles (Anjum et al., 2013, 2015). Thus, plants and animals/humans are being significantly exposed to nanoparticles diversity through various pathways. Potential benefits of nanotechnologies have been welcomed in diverse sectors including plant health-improvement (Seabra et al., 2013; Husen and Siddiqi, 2014; Iravani et al., 2015), animal/human health and medicine (Cooper et al., 2014; Bhavsar et al., 2015; Cheng et al., 2015), and environmental decontamination (Ram et al., 2011; Mohmood et al., 2013; Sharma et al., 2013; Perreault et al., 2015). However, owing to the existence of a close link between the components of the plant-animal/human system, the contamination of animal/human food with manufactured nanoparticles *via* plant and/or plant-based products has become a major challenge for life and environmental scientists. This situation can be further aggravated by a lack of discussion and poor understanding on the engineered nanoparticle-interaction with the plant-animal/human system (Fig. 2). Additionally, indiscriminate and multidisciplinary use without aftermath knowledge on the fate, behavior and consequences of nanoparticles in the environment and their interaction with the biological systems can help negative effects to surpass the nanoparticle-lead opportunities, thus undermining the sustainable development of rapidly growing field of nanotechnology (Fig. 3).

Given the above, this note briefly discusses and interprets the facts related with the mainstay of 'transport phenomenon' of nanoparticles in the plant-animal/human system. The outcome of the discussion can provide clues important for the improvement of the plant-animal/human health as well as for their protection against potential toxic consequences on nanoparticles.

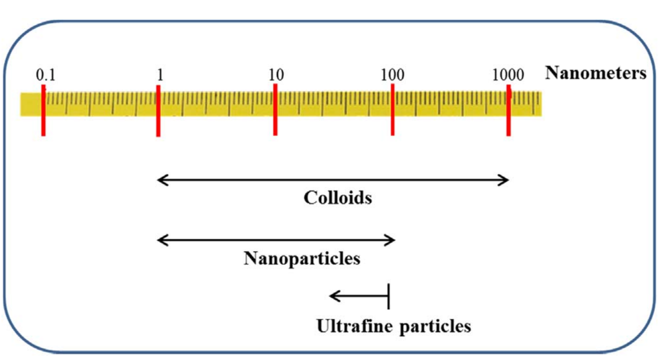

Fig. 1. Different classes of nanoparticles according to their size (*Modified after- Nowack and Bucheli, 2007*).

2. Transport phenomena of nanoparticles in plants

Plants strongly interact with their surrounding environment often contaminated with hazardous substances, including nanoparticles, thus becoming vulnerable to their potential effects. Since metal-based nanoparticles (MNPs) have extensive applications due to their unique physico-chemical properties and multidisciplinary applications, potential exposure of plants to MNPs has been considered the highest priority study subject (Anjum et al., 2013, 2015; Peng et al., 2015). Nevertheless, interaction of widely developing genetically modified/transgenic crops with extensively synthesized and applied nanoparticles can also be not ignored (Le et al., 2014; Li et al., 2014). Notably, human and animal systems can be at great risk *via* nanoparticles-laden plants or plant-based food products. Despite the previous fact, literature is scarce primarily on nanoparticles-plant interaction and secondarily on the transport phenomena of nanoparticles in plants (Ma et al., 2010; Sabo-Attwood et al., 2012; Anjum et al., 2013, 2015; Deng et al., 2014). Hereunder, efforts are made to appraise recent literature available on the subject to briefly highlight potential processes and mechanisms underlying nanoparticle-uptake/accumulation and root-harbored nanoparticle transport to leaves and edible plant parts (Fig. 4a).

2.1. Nanoparticle-plant root interaction and its regulation

Leaves can be one of the major routes for the entry of nanoparticles into the plant system *via* leaf spray, injection and atmospheric exposures (Corredor et al., 2009; Birbaum et al., 2010; Deng et al., 2014). However, roots can be both the primary plant organ close to the soils potentially contaminated with the types of nanoparticles, and also the major entry point of nanoparticles for other plant organs as well as for plant-based foods and human/animal system (Anjum et al., 2013, 2015). Processes such as adsorption, translocation and accumulation of nanoparticles can be modulated by plant types and also by the size, type, chemical composition and stability of nanoparticles (Rico et al., 2011). Nevertheless, contingent to types of nanoparticles and plants, and also the experimental conditions, the bioavailability of nanoparticles to plants can be different. Additionally, a differential nanoparticle adsorption and absorption can also be possible in roots. Nevertheless, plants are being used for the synthesis of various nanoparticles in order to ascertain their benefits in plants, and also to confirm and understand important phenomena for nanoparticles-delivery in the target tissue/organs/cells/cell organelles (Narayanan and Sakthivel, 2010; Basavegowda et al., 2014; Rajasekharreddy and Rani, 2014; Mittal et al., 2013; Noruzi, 2015; Manivasagan et al., 2015; Kumari et al., 2015; Servin et al., 2015; Silva et al., 2015). However, reports thus far available in this regard