Marine Environmental Research 111 (2015) 128–134

Contents lists available at ScienceDirect

Marine Environmental Research

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

Interactive effects of nanoparticles with other contaminants in aquatic organisms: Friend or foe?

L. Canesi [a, *], C. Ciacci [b], T. Balbi [a]

[a] Dept. of Earth, Environmental and Life Sciences-DISTAV, University of Genoa, Italy
[b] Dept. of Earth, Life and Environmental Sciences-DiSTeVA, University of Urbino, Italy

ARTICLE INFO

Article history:
Received 9 January 2015
Received in revised form
25 March 2015
Accepted 29 March 2015
Available online 31 March 2015

Keywords:
Aquatic organisms
Nanoparticles
Contaminants
Interactive effects
Mytilus

ABSTRACT

The increasing production and use of nanoparticles (NPs) will lead to their release into the aquatic environment, posing a potential threat to the health of aquatic organisms. Both in the water phase and in the sediments NPs could mix and interact with other pollutants, such as organic xenobiotics and heavy metals, leading to possible changes in their bioavailability/bioconcentration/toxicity. However, whether these interactive effects may lead to increased harmful effects in marine organisms is largely unknown. In this work, available data mainly obtained on carbon based NPs and n-TiO_2, as examples of widespread NPs, in aquatic organisms are reviewed. Moreover, data are summarized on the interactive effects of n-TiO_2 with 2,3,7,8-TCDD and Cd^{2+}, chosen as examples of common and persistent organic and inorganic contaminants, respectively, in the model marine bivalve *Mytilus*. The results reveal complex and often unexpected interactive responses of NPs with other pollutants, depending on type of contaminant and the endpoint measured, as well as differences in bioaccumulation. The results are discussed in relation with data obtained in freshwater organisms. Overall, information available so far indicate that interactive effects of NPs with other contaminants do not necessarily lead to increased toxicity or harmful effects in aquatic organisms.

1. Introduction

The increasing production and usage in various fields of different types of manufactured nanomaterials, estimated to grow to over half a million tons by 2020, would lead to their release in substantial amounts in the environment, including the aquatic compartment. This in particular applies to those types of nanoparticles (NPs) produced in higher amounts, such as metal-oxides (silver, titanium dioxide, zinc oxide, silica), and carbon-based NPs (fullerenes including single- and multi-walled carbon nanotubes), thus raising considerable concern on their environmental behavior (aggregation/agglomeration, redox reactions, dissolution, exchange of surface moieties, and reactions with biomacromolecules) and consequent impact on aquatic organisms (Delay and Frimmel, 2012; Matranga and Corsi, 2012; Gottschalk et al., 2013; Baker et al., 2014; Corsi et al., 2014).

Due to their extremely small size, NPs exhibit unique physicochemical properties such as high specific surface area and increased reactivity, which accounts for their widespread use in a number of industrial and biomedical applications. Among these, certain NPs are utilized for environmental remediation (wastewater treatment), due to the high adsorption capacity for metals and organic compounds (Sanchez et al., 2011). However, the inherent properties of NPs can represent a double-edged sword in an environmental context when released into the aquatic compartment. Both in the water phase and in the sediments, NPs will mix and interact with other components, not only dissolved and particulate organic matter, but also hydrophobic organic contaminants and inorganic ions, including heavy metals (Maurer-Jones at al., 2013; Baker et al., 2014; Corsi et al., 2014; Grillo et al., 2014). How these interactions may affect the biological impact of NPs *per se* or that of other pre-existing contaminants is largely unknown, and is therefore the subject of considerable debate.

Limbach et al. (2007) first postulated the '*Trojan horse*' effect, that implies facilitated entry of toxic molecules adsorbed to NPs into the cells. Baun et al. (2008) extended this concept in an environmental context, recommending that risk assessment of NPs should not only focus on their inherent toxicity, but also consider

* Corresponding author. DISTAV-Dipartimento di Scienze della Terra, dell'Ambiente e della Vita, Università di Genova, Corso Europa 26, 16132 Genova, Italy.
E-mail address: Laura.Canesi@unige.it (L. Canesi).

http://dx.doi.org/10.1016/j.marenvres.2015.03.010
0141-1136/

Table 1
Studies of co-exposure to carbon-based NPs and other contaminants in aquatic organisms.

Species/Time of exposure	Type of Particle/ Concentration	Type of contaminant/ Concentration	Target cell/ Tissue/Organism	Endpoint/Interactive effect	Contaminant accumulation	Reference
Freshwater						
C. vulgaris	**MWNCTs**	**Diuron**	whole organism			Schwab et al., 2013
3–6–15–24 h	10 mg/L	0.73–2990 μg/L		Increased toxicity (inhibition of photosynthetic activity) due to increased diuron bioavailability		
O. latipes	**SWNCTs**	**Phenanthrene**	digestive tract/tissues			Su et al., 2013
1–4–12–24–72 h	15 mg/L	60 μg/L			72 h: Facilitated the accumulation of Phe in the digestive tract and increased concentrations in liver and brain	
C. auratus	**OH-MWNCTs**	**Cd^{2+}**	liver			Qu et al., 2014
3-12 d	0.5 mg/L	0.1 mg/L		12 d: Inhibition of SOD, CAT, GPx activities and decrease in GSH level (synergistic effect); Increase in MDA content (3–12 d)	12 d: Increased Cd^{2+} concentration	
D. rerio	**C60 fullerene**	**As(III)**	hepatocytes			Azevedo Costa et al., 2012
4 h	1 mg/L	2.5 μM		Antagonistic effects on GSH and TBARS concentration	Increased As concentration	
		100 μM		Decreased intracellular ROS concentration and GST Ω activity		
D. rerio	**C60 fullerene**	**B[a]P**	hepatocytes			Ferreira et al., 2014
4 h	1 mg/L	0.01–0.1–1 μg/L		Lowered cell viability; Reduced intracellular ROS concentration		
		0.1–1 μg/L		Impaired Phase II detoxification response to B[a]P (GST activity)		
		1 μg/L			Increased accumulation of B[a]P	
D. magna	**C60 fullerene**	**Phenanthrene**	whole organism			Baun et al., 2008
P. subcapitata						
48 h	3 mg/L	49 μg/L			Faster Phe uptake	
	6 mg/L	μg/L range		Increased toxicity in *P. subcapitata*; Decreased toxicity in *D. magna*		
	C60 fullerene	**Pentachlorophenol**	whole organism			
	5–8 mg/L	μg/L range		Decreased toxicity (EC50) for both organisms		
	C60 fullerene	**Methyl Parathion**	whole organism			
	6–8 mg/L	μg/L range		No changes in toxicity		
	C60 fullerene	**Atrazine**	whole organism			
	10 mg/L	μg/L range		No statistically significant changes in toxicity in algae		
D. magna	**C60 fullerene**	**Fluoranthene**	whole organism			Yang et al., 2010
1 d	3 mg/L	5 μg/L		Significant decrease in toxicity (LT50 immobilization test)		
1 d	22 mg/L + UV	5 μg/L		Antagonistic effect on fluoranthene photo-induced toxicity		
D. rerio	**C60 fullerene**	**17α-ethinylestradiol**	whole organism/liver			Park et al., 2010
5 d	mg/L range	1 μg/L		Sorbption to C60 resulted in 100% reduced toxicity of the compound; Antagonistic effect on bioavailability of EE2 (reduced induction og vtg1A/B)		
Marine						
M. edulis	**C60 fullerene**	**Fluoranthene**				Al-Subiai et al., 2012
72 h	0.1 mg/L	32 μg/L	hemocyte	Additive effect on genotoxic biomarkers (Comet assay)		
			adductor muscle	Synergistic increase in Glutathione content		
			gills/digestive gland/ adductor muscle		Reduced accumulation of C60	