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Nanoparticles cyto and genotoxicity in plants: Mechanisms and abnormalities

Saeed Karami Mehrian[a,*], Renata De Lima[b]

[a] Young Reserachers and Elite Club, Yasooj Branch, Islamic Azad University, Yasooj, Iran
[b] Department of Biotechnology, University of Sorocaba, Sorocaba, SP, Brazil

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ABSTRACT

This report presents an overview related to genotoxicity and the cytotoxicity of nanoparticles in plants in order to better understanding of NPs (nanoparticles) interactions with DNA, chromosomes components, nuclear proteins and,etc. Genotoxicity of NPs has been poorly studied in plants, and majority of studies have focused on mammalian and bacteria cytotoxicity. Therefore further studies in plants field are required. Nanoparticles induce genotoxicity as either direct or indirect mechanisms. In direct genotoxicity NPs after passing through the cell and nucleus membrane through diffusion or endocytosis mechanisms could interact directly with the DNA mechanically or by chemical binding to DNA. Indirect genotoxicity resulting from interaction of NPs with the nuclear proteins (proteins involve in replication, transcription, translations, microtubule, microfilaments, and centrioles) or stress oxidative induced by reactive oxygen species and also by reduced DNA repair functions. Genotoxicity as a biotic response to NP exposure increases with decreasing in NPs size and increasing in concentration and exposer duration, which leads to an inhibitory effect on cell cycle. Micronuclei formation, disturbed chromosomes, chromosome fragments, stickiness, bridge, laggards' chromosomes and decrease in mitotic index are the most obvious anomalies in plants exposer to silver, copper, titanium dioxide, zinc, zinc oxide, selenium oxide, multi wall carbon nano tube, Tetramethylammonium hydroxide and Bismuth (III) oxide nanoparticles. The severity of abnormalities depending on the concentration, duration time and particle size are different. Finally if the DNA repair mechanisms were not enough to overcome this crisis (genotoxicity), it can lead to loss of genetic material and mutation in DNA.

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* Corresponding author.
E-mail address: saeidkaramii@yahoo.com (S. Karami Mehrian).

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1. Introduction

Developments of the past decade in the field of nanotechnology and agriculture has shown that the nanotechnology has the potential to revolutionize the agro technologies, which could lead to the commercialization of nanobased products, such as nanofertilizers, nanofungicides, pesticides, etc (Nagaonkar et al., 2015). Despite these potential advantages, a lot of issues still not addressed. For instance, the growing public debate on the toxicity and environmental impact of direct and indirect exposures to nanoparticles (Brayner, 2008; Panda et al., 2011). NPs because of their nano-sized agglomerates have been the subjects of most researches and are used in various industries due to their unique electronic, optical, mechanical, magnetic and chemical properties that are different from those of bulk materials (Masarovicova and Kralova 2013; Wise et al., 2010). Wide variety of toxicological effects of nanoparticles on human (Asharani et al., 2009), environment (Benn and Westerhoff, 2008), bacteria (Choi and Hu, 2008) and aquatic organisms (Meyer et al., 2010) has been reported. NPs can interact with biological macromolecules such as nuclear (e.g. DNA), cytosolic components (e.g. proteins and enzymes), lipids and other cellular components (Mahmoudi et al., 2011; Aggarwal et al., 2009; Asharani et al., 2009) and leading to depletion of electron/ion transport chain through cell membranes (Teodoro et al., 2011) production of reactive oxygen species (ROS) (Celardo et al., 2011) genotoxicity (Singh et al., 2009) and structural reconstruction and phase transition of the cell membrane (Li and Gu, 2010). Genotoxicity is one of the most devastating effects that NPs could have on plants. Although researches in genotoxicity in the field of plants is not much, but all these researches have revealed genotoxic effects of various NPs in various plants. Different chromosome abnormality such as chromatin bridge, stickiness, disturbed metaphase and chromosomal breaks was observed in *Vicia faba* root-tips exposed to AgNPs (Patllola et al. (2012), *Allium cepa* root tips meristems exposed to zinc oxide nanoparticles (ZONPs) (Kumari et al., 2011) and *A. cepa* root-tip cells exposed to silver nanoparticles (AgNPs) (Panda et al., 2011). Decrease in mitotic index (MI) and micronuclei formation under the influence of NPs was reported in plants (Patllola et al., 2012; Kumari et al., 2011; Panda et al., 2011). Increase in fraction of the atoms at the surface of NPs introduces a high surface/volume ratio as an additional dimension in regulating NP interfacial properties (Nel et al., 2009) that lading to dictate interactions with biosystems (Saha et al., 2011; Stark, 2011) and determining the nontoxicity in biological and environmental systems refereeing to the role of this interactions (Xia et al., 2009; Handy et al., 2008a, 2008b). Many references are cited in this review article, which some of them was entered from animal field. Because the mechanisms and some aspects of genotoxicity in the field of animal fully investigated, and so far, it has not been investigated in the field of plants. In this review we have tried to discuss mechanisms of entry of NPs and genotoxicity, also different types of abnormalities induced under NPs exposer. Determine the most important factor in the interaction of NPs with live organisms is a scientific challenge that requires a detailed understanding of the characteristics, properties and classification of the nanomaterials. To the best of our knowledge this is the first review article related to NPs toxicity and genotoxicity mechanisms in plants.

2. NPs features classification and usage

Nanomaterials for two reasons behave different than bulk materials: A: surface effects (increased fraction of the atoms at the surface in NPs). B: Quantum effects (the physics of electron properties with reductions in particle size) (Roduner, 2006) which can affect the chemical reactivity of materials and can leading to interaction with living organisms (Rizzello and Pompa, 2014; Astruc, 2012; Ye et al., 2012; Farre et al., 2011) or intrinsic toxicity of the surface which is a significant cause of concern (Das and Ansari, 2009; Donaldson et al., 2004). NPs enter living systems through anthropogenic and natural releases such as solid/liquid waste streams from manufacture facilities and atmospheric emissions (Dutschk et al., 2014). Dimensionality, morphology, composition, uniformity, and agglomeration are the NPs classification criteria (Buzea et al., 2007), NPs are spherical, tubular, irregular in shaped and also exist in aggregated, agglomerated and fused forms (Nowack and Bucheli, 2007). Based on dimensionality they are classified to one, two, three or more nanomaterials (NMs) dimension. Despite different classifications, one of the most widely used classifications is based on NPs composition (e.g., U.S. EPA, 2007): According to NPs composition there are four groups: (1) carbon-based materials (e.g., C60 fullerene and MWCNT). (2) metal-based substances (e.g., Ag, Au, and NPO). (3) Dendrimers, polymers consisting of branched units. (4) bio-inorganic complexes (e.g., NPs such as titanium with attached DNA strands) (U.S. EPA, 2007).

Also NPs are different according to their classification, composition and source derivation. As photochemical reactions, volcanic eruptions, forest fires, erosion, plants and animals (shedding of skin and hair) are considered as natural sources of NPs derivation. Manufactured NPs are also considered as anthropogenic sources of NPs derivation (Nowack and Bucheli, 2007; Biswas and Wu, 2005; Tervonen et al., 2009; Buzea et al., 2007). NPs are used in different areas, such as electronic, biomedical, pharmaceutical, cosmetic, energy, environmental, catalytic and etc (Nowack and Bucheli, 2007). Among the available nano-sized materials, AgNPs owing to its potent antimicrobial activity (Durán et al., 2010) are by far the most used nano compounds (Ahmed et al., 2008). Blaser et al. (2008) estimated the production of silver – containing products about 110–230 t by 2010 in Europe, and then stabilize by 2015, this is also confirmed by Fabrega et al., 2011; who state that the silver production worldwide 2011 was about 500t. Blaser et al. (2008) also reported that in 2010 15% of emitted silver in water was going to be from biocidal plastics and textiles. On one hand reports of the growing use of nanoparticles, and on the other hand numerous reports related to the toxicity of these nanoparticles is located. As many authors reported that the silver ions have been found to be toxic to several organisms such as bacteria, algae and fungi (Wood et al., 1996; Ratte, 1998; Moore, 2006; Choi et al., 2008; Navarro et al., 2008). Zinc oxide (ZnO) is other widely used metal oxide NP that has an excellent UV absorption and wurtzite crystal structure due to its optoelectric properties (Wang, 2004). ZnONPs are used in a broad range of products including plastics, ceramics, glass,

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