

The translocation and distribution of CeO₂ nanoparticles in plants (Soybeans, Chili, Eggplant and Tomato)

Teng Li and Yanhui Dai*

Key Laboratory of Marine Environment and Ecology, Ministry of Education and College of Environmental Science and Engineering, Ocean University of China, Qingdao 266100, China

*Corresponding author e-mail: yanhui1437@163.com

Abstract. Intensive production of CeO₂ nanoparticles (NPs) would lead to their release into the environment. While their use in commercial goods is constantly increasing, location of NPs in plant is still poorly documented. In this study we determined the translocation of CeO₂-NPs in four plants (Soybeans, Tomato, Chili and Eggplant) grown in natural conditions. The plants were digged out 1/4 roots into 2000 mg/L CeO₂-NPs solution during the blossoming period. After being exposed for one month, the contents of Ce in plant tissues were measured by inductively coupled plasma mass spectrometry (ICP-MS). There was more Ce in the leaf of treated plants than in control plants. The contents of Ce in leaf tissues was different. This research offers vital information about the translocation and distribution of CeO₂-NPs in higher plants.

1. Introduction

Engineered nanoparticles (NPs) have inevitably led to their release into the environment due to wide commercial and industrial applications [1]. They have been widespread application in many fields, such as UV-blockers, gas sensors [2], catalysts for augmenting fossil fuel oxidation [3], solid state fuel cells, polishing agents, etc [4]. They are potentially harmful to environmental organisms and human health through the food chains because of wide use of NPs in agriculture [5].

Plants are an important part of the ecosystem. Assessing the transport and bioaccumulation of NPs in terrestrial plants will help us to understand the risk of NPs to human through food chain [6–7]. Numbers of studies had investigated the translocation and bioaccumulation of NPs in hydroponic plants [8–10]. Most of these works concluded a dose-dependent and time-dependent effects of Ce contents in plant tissues by inductively coupled plasma mass spectrometry (ICP-MS). Moreover, most CeO₂ NPs could adsorb on the root surface and be taken into roots and only a limited quantity of them could be transformed from roots to shoots.

Although the transfer of CeO₂ NPs in hydroponic plants had been reported in several studies, there are few studies about the exposure of nanoparticles to plants which were grown in the natural conditions and the detailed distribution of CeO₂ NPs in leaves was lack of research. In this study, we investigated the translocation of CeO₂ NPs in four plants growth in natural conditions, and determined the detailed distribution of CeO₂ NPs in leaves.

2. Materials and methods

2.1. Chemicals and seeds



Soybeans, Tomato, Chili and Eggplant seeds were purchased from Qingdao Seed Station and kept at 4°C for further use. The mean germination rates of four plants were more than 85%. CeO₂ nanoparticles (NPs) were purchased from Sigma Aldrich (USA). Other chemicals were purchased from Sinopharm Chemical Reagent Co. Ltd (China).

2.2. Characterization of CeO₂ NPs

Hydrodynamic diameter and zeta-potential of NPs in ultrapure water were determined by dynamic light scattering (ZetaSizer, Malvern Instruments, Worcestershire, UK). Determine the CeO₂ NPs particle morphology and size by TEM (JEM 200CX, Japan).

2.3. Plant culture and nanoparticles application

A farmland in Qingdao agricultural Science Institute was used for the cultivation of Soybeans, Tomato, Chili and Eggplant. CeO₂ NPs powders were mixed with ultrapure water to obtain the CeO₂ suspension by ultrasonication for 30 min, of which the final concentration was 2000 mg/L. The plants were maintained in normal growth. And after the blossom, the plants were chosen to dig out 1/4 roots to 50 ml triangular flask with 2000 mg/L CeO₂ NPs and the rest of the roots grow normally in the soil. The plants in ultrapure water were considered to control group. Due to the aggregation of NPs, the NPs culture medium was replaced every three days for one month.

2.4. Determination of Ce content in plants

After 1 month exposure, plants tissues (old leaves, new leaf, fruit, untreated roots, rhizosphere soil) were acquired and rinsed with flowing tap water and deionized water thoroughly [11]. Samples were dried for two days in the oven for 70°C until to the constant weight. To determine the Ce contents, the dried samples were ground to fine powders and digested with a HNO₃/H₂O₂ mixture by microwave digestion (MARS 6 CLASSIC, CEM, USA). Total Ce contents in the tissues were determined using inductively coupled plasma–mass spectrometry (ICP-MS, Thermo, USA) [12].

2.5. Determination of Ce distribution in leaf

In order to determine the Ce detailed distribution, leaves were dividing to five parts (leaf bases, leaf veins, leaf apex, leaf margin and mesophyll) and the Ce content was measured in each part.

2.6. Statistical analysis

The results were expressed as mean ± SD (standard deviation). Each treatment was replicated three times. One-way ANOVA followed by Tukey's HSD test was employed to examine the statistical differences. P<0.05 showed significant difference.

3. Results and discussion

3.1. The characterization of CeO₂ nanoparticles in suspension

50 mg/L CeO₂ NPs suspension was used for measurement of hydrodynamic diameter and Zeta potentials. Hydrodynamic diameter and Zeta potentials of CeO₂ NPs in deionized water were 264.70±31.34 nm and 27.6±2.13 mV. The exhibit octahedral morphology and uniform size distribution of CeO₂ NPs was shown by TEM (Figure.1).

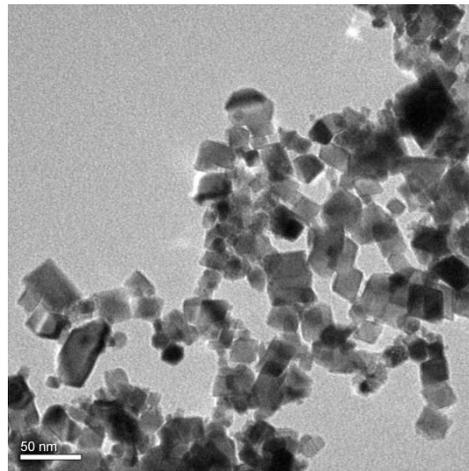


Figure 1. TEM image of the CeO₂ NPs.

3.2. Ce content in plants tissues

As shown in Figure 2, there were no different Ce content in the four kinds of unexposed roots and in rhizosphere soil compared to control, indicating that the NPs were not transported to the unexposed roots, nor did transport to the soil. The results were somewhat different from the previous reports, for example, a report of root-to-shoot-to-root redistribution after transformation of CeO₂ NPs in plants [13]. That may be due to the different plants and different ways of cultivation. There were also no Ce found in the fruit.

There were about 20 mg/kg Ce in the leaves of soybeans, tomato and chili and about 40 mg/kg Ce in eggplant leaves. But Ce content in new leaves were less than old leaves, just about half of old leaves. This may be due to that new leaves don't need Ce from old leaves, and there was a time-dependent increase of Ce contents in plant tissue.

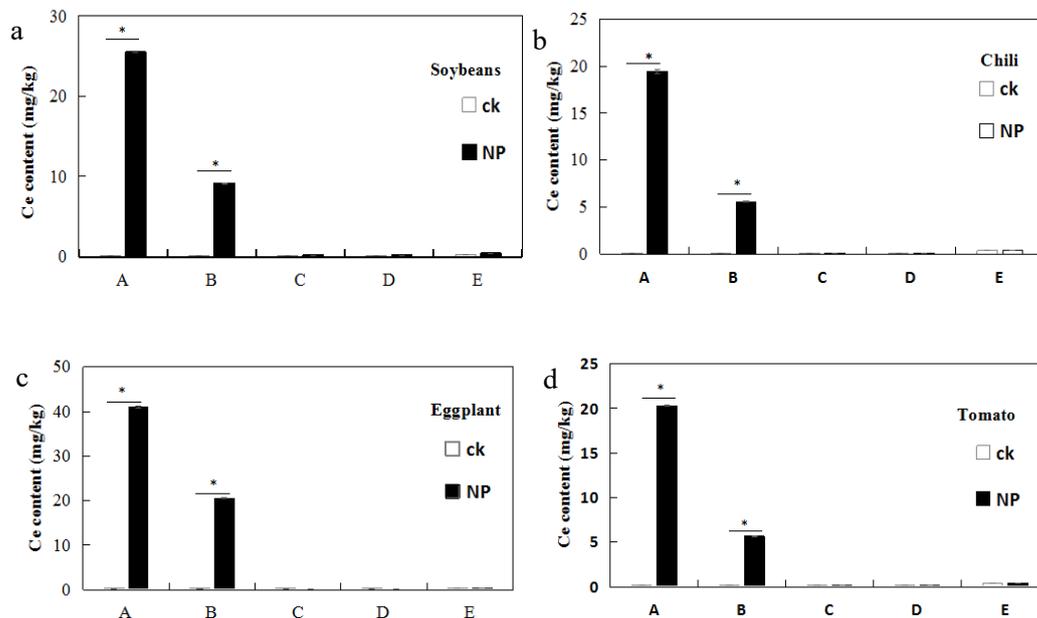


Figure 2. The concentration of Ce in plants tissues, a/b/c/d mean four kinds of plants(Soybeans, Chili, Eggplant and Tomato). A/B/C/D/E mean old leaves, new leaves, fruits, untreated roots and rhizosphere soil, respectively. ‘*’ denotes difference ($p < 0.05$).

3.3. Detailed distribution of Ce in leaf

In the previous study, we found that there were more Ce in the old leaves. Thus, in the next study, we focused on the detailed distribution of Ce in the old leaves. As shown in figure 3, there was about 52.89% Ce distributed in leaf bases, about 23.78% Ce in leaf veins and the rest Ce in leaf apex, leaf margin and mesophyll. It was indicated that Ce was transported through the catheter in the leaves and distributed in various locations of the leaves.

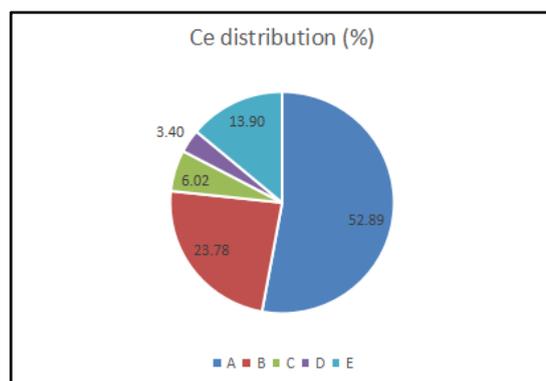


Figure 3. The distribution of Ce in the leaves, A\B\C\D\E mean leaf bases, leaf veins, leaf apex, leaf margin and mesophyll.

4. Conclusion

In summary, although 1/4 roots of plants exposed in 2000 mg/L CeO₂ NPs, Ce still transported from roots to the overground part. The concentration of Ce was more than half in the leaf bases and Ce was transported through the catheter in the leaves and thus distributed in various locations of the leaves. This result will help to understand the translocation and distribution of other metal-based NPs in environment.

Acknowledgments

The research was supported by NSFC (41530642).

References

- [1] Gottshalk, F.; Sonderer, T.; Scholz, R. W.; Nowack, B. Modeled environmental concentrations of engineered nanomaterials (TiO₂, ZnO, Ag, CNT, Fullerenes) for different regions. *Environ. Sci. Technol.* 2009, 43, 9216–9222.
- [2] Liao, L.; Mai, H.; Yuan, Q.; Lu, H.; Li, J.; Liu, C.; Yan, C.; Shen, Z.; Yu, T. Single CeO₂ nanowire gas sensor supported with Pt nanocrystals: Gas sensitivity, surface bond states, and chemical mechanism. *J. Phys. Chem. C* 2008, 112 (24), 9061–9065.
- [3] Garcia, T.; Solsona, B.; Taylor, S. H. Nano-crystalline ceria catalysts for the abatement of polycyclic aromatic hydrocarbons. *Catal. Lett.* 2005, 105 (3–4), 183–189.
- [4] Cassee, F. R.; Van Balen, E. C.; Singh, C.; Green, D.; Muijser, H.; Weinstein, J.; Dreher, K. Exposure, health and ecological effects review of engineered nanoscale cerium and cerium oxide associated with its use as a fuel additive. *Crit. Rev. Toxicol.* 2011, 41 (3), 213–229.
- [5] Khot, L.R., Sankaran, S., Maja, J.M., Ehsani, R., Schuster, E.W., 2012. Applications of nanomaterials in agricultural production and crop protection: a review. *Crop Prot.* 35, 64–70.
- [6] D. Stampoulis, S. K. Sinha and J. C. White, *Environ. Sci. Technol.*, 2009, 43, 9473–9479.
- [7] H. Zhu, J. Han, J. Q. Xiao and Y. Jin, *J. Environ. Monit.*, 2008, 10, 713–717.
- [8] Zhang, Z.; He, X.; Zhang, H.; Ma, Y.; Zhang, P.; Ding, Y.; Zhao, Y. Uptake and distribution of ceria nanoparticles in cucumber plants. *Metallomics* 2011, 3 (8), 816–822.
- [9] Schwabe, F.; Schulin, R.; Limbach, L. K.; Stark, W.; Bürge, D.; Nowack, B. Influence of two types of organic matter on interaction of CeO₂ nanoparticles with plants in hydroponic culture.

- Chemosphere 2013, 91 (4), 512–520.
- [10] Majumdar, S.; Peralta-Videa, J. R.; Bandyopadhyay, S.; CastilloMichel, H.; Hernandez-Viezcas, J. A.; Sahi, S.; Gardea-Torresdey, J. L. Exposure of cerium oxide nanoparticles to kidney bean shows disturbance in the plant defense mechanisms. *J. Hazard. Mater.* 2014, 278, 279–287.
- [11] Zhang P, Ma Y, Liu S, et al. Phytotoxicity, uptake and transformation of nano-CeO₂ in sand cultured romaine lettuce[J]. *Environmental Pollution*, 2017, 220: 1400-1408.
- [12] Zhang, P.; Ma, Y.; Zhang, Z.; He, X.; Guo, Z.; Tai, R.; Ding, Y.; Zhao, Y.; Chai, Z. Comparative toxicity of nanoparticulate/bulk Yb₂O₃ and YbCl₃ to cucumber (*Cucumis sativus*). *Environ. Sci. Technol.* 2012, 46, 1834–1841.
- [13] Ma Y, He X, Zhang P, et al. Xylem and Phloem Based Transport of CeO₂ Nanoparticles in Hydroponic Cucumber Plants[J]. *Environmental Science & Technology*, 2017, 51(9): 5215-5221.