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Phytotoxicity of nano-zinc oxide to tomato plant (*Solanum lycopersicum* L.): Zn uptake, stress enzymes response and influence on non-enzymatic antioxidants in fruits

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Highlights

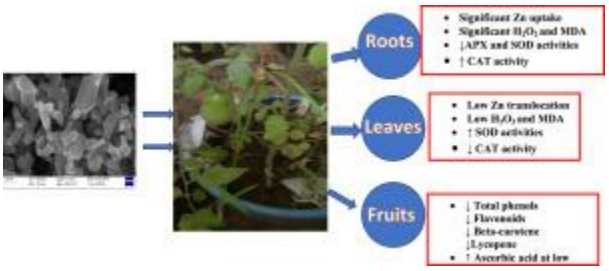
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Zn uptake was significant in roots with reduced translocation to shoots.

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  Increased APX and SOD activity levels, coupled with lipid peroxidation in roots.
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  Contents of non-enzymatic antioxidants were significantly altered in fruits.

Abstract

The production of metallic nanoparticles is greatly increasing due to its wide range of applications in agricultural formulations. The present pot experiment investigated the uptake of Zn from nano-zinc oxide (n-ZnO)-amended soil at 300, 600 and 1000 mg n-ZnO/kg concentrations, and its effects on the enzymatic and non-enzymatic antioxidants in tomato tissues and fruits respectively. Results showed that root uptake of Zn increased with increasing n-ZnO concentrations. The enzyme activity showed that n-ZnO, through the generation of $H2O_2$ and induction of oxidative stress, significantly reduced the activity of stress-controlling enzymes (APX and SOD) in the root. Conversely in leaves, despite alteration in chlorophylls in the early growing stage, APX activity was only significant at 1000 mg n-ZnO/kg) while SOD activity was enhanced at all treatments. CAT activity was significantly reduced, unlike in the roots where CAT activity was significantly enhanced. Contents of total phenols, flavonoids, β-carotene and lycopene in fruits were significantly reduced by at least 4.8% while ascorbic acid was promoted at low n-ZnO treatments. In conclusion, the toxic effect of n-ZnO on stress enzymes was prominent in tomato roots, and there was also inhibitory effect on induction of non-enzymatic antioxidants in the tomato fruits.

Graphical abstract



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Introduction

Agriculture is the main nexus between humans and the environment, and portends major cause of soil and ecosystem modification. Agriculture is also an economic activity that is recently engaging the applications of nanotechnology and consequently leading to a new emission source of nanoparticles and nanomaterials into the environment and food chains (Scott and Chen, 2013). Nanoparticles have great potential to improve the agricultural productivity, especially in the area of nano-fertilizers (NF). Mineral nutrients encapsulated in NF forms promote plant nutrition (Fedorenko et al., 2015, Mohammad et

al., 2017), and offer greater solubility with rapid absorption or less leaching, compared with conventional fertilizers. It is imperative to state that the problem associated with plants' mineral nutrition is not actually the amount of element (s) present in the soil but rather their phytoavailability (Plibeam, 2015). For this reason, the encapsulation of fertilizers and other compounds in inorganic nanomaterials such as nanotubes of carbon and metals has been explored (Liu et al., 2009).

Nanoparticles (NPs) are introduced into soil environment from multiple human activities, and the accompanying eco-risks have not been fully understood (Cai et al., 2006). Zinc nanoparticles (Zn NPs) are among the most commonly used nanomaterials, especially in agriculture, cosmetology, medicine and as antibacterial agent. Zinc oxide nanoparticles (ZnO NPs) are reported to possess efficient screen for a broader UV range than any of the molecular UV-absorbers, photocatalytic degradation of environment pollution, biocompatibility in drug delivery mechanisms and as nanofertilizers and nanopesticides (Kulkarni and Muddapur, 2014, Sabir et al., 2014).

However, aside the potential importance, ZnO NPs pose increased ecological and human health risks because of possible interaction with various components of the environment (Chithrani et al., 2006). The presence of elevated content of ZnO NPs in soil may affect plant growth and functioning due to its potential toxicity when internalized and accumulated in large amounts in plant tissues (Ma et al., 2009, Ma et al., 2011). Several studies have reported the toxicity potential of ZnO NPs to crop plants such as broad bean (Manzo et al., 2011), lettuce, radish, cucumber (Lin and Xing, 2007), wheat Du et al. (2011) and zucchini (Stampoulis et al., 2009).

Tomato is of great importance worldwide with more than 80% of grown tomatoes processed into edible products such as tomato juice, paste, sauce etc. (Kadar et al., 1977). Fruit of tomato is rich in nutrients such as organic acids, sugars, dietary fiber, pectic substances, proteins, minerals, vitamins, and carotenoids possessing antioxidant qualities (lycopene, β-carotene, etc.). Although, the toxicity of nanoparticles has been evaluated through a variety of routes such foliar and hydroponic applications, to the best of the authors knowledge, no study has evaluated the effect of nano-zinc oxide (particle size < 100 nm) through particulate application via soil medium on tomato plant and its fruits. Therefore, the study aimed to (i) investigate the uptake of Zn and bioaccumulation, (ii) evaluate the response of stress enzymes in roots and leaves to n-ZnO and, (iii) assess the level of selected non-enzymatic antioxidants in the fruit of tomato grown in nano-ZnO-amended soil. It is the authors' belief that the results of the experiment would further enrich scientific information on the ZnO NPs-plant system interactions.