Zinc Sulphide Nanoparticle as an alternative source of Zinc Micronutrient for Crop Growth and Yield: Application and Evaluation

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Abstract: In spite of extraordinary properties of zinc sulphide nanoparticle (nZnS), its role on plant system is not well understood, yet. Therefore, this study was aimed to assess the effects of nZnS in mung bean (*Vigna radiata*) plant. This study was divided into two parts. First part contains preliminary 10 days study where, nZnS was synthesized by modified reflux method and physicochemical characterizations were conducted. Then, the effects of nZnS on mungbean plants at 0, 0.1, 0.5 and 1 mg L^{-1} concentrations were determined by seed germination, growth parameters, membrane integrity and ROS-antioxidant defense assays. The effect of nZnS on nutritional status of mungbean plants was also determined. Our results showed that nZnS treatment has significantly increased seed germination, root-shoot length, pigment content, nutritional status and decreased lipid peroxidation. There were increased total antioxidant activity (TAA), DPPH and flavonoid contents found in treated plants. Also, nZnS treatment did not activate oxidative stress determined by SOD, CAT, CPX, APOX and GR activities. The uptake and translocation of nZnS in mungbean plants were determined by Transmission Electron Microscope (TEM) and Scanning Electron Microscope (SEM). Besides, electron micrographs showed no alteration in cell structures between treated and control plants, further confirming that nZnS treatment has no phytotoxic effects. Again, genotoxicity and cytotoxicity study confirmed no toxic effect of nZnS. In vitro and in vivo studies on Zn release from nZnS were also determined using Inductively Coupled Plasma Mass Spectroscopy (ICPMS) and Energy Dispersive X-ray (EDX), which showed that the Zn release and particles uptake were concentration dependent. Overall, results of this study demonstrated the positive role of nZnS on growth, nutritional status and antioxidant defense responses in *V. radiata* at the selected concentrations. Second part contains the life cycle study where, a comparative study was done with nZnS, nZnO and $ZnCl_2$ at different concentrations (0, 0.01, 0.1, 1 and 10 mg kg^{-1} of soil). Results showed that both the NPs, (nZnS and nZnO) were more effective than $ZnCl_2$ salt in promoting growth and yield up to a critical concentration and above which phytotoxic effects were observed. Both the NPs were more effective than $ZnCl_2$ at increasing fruit Zn content also. Whereas, nZnS treatment was found to be more effective than nZnO in improving overall plant growth. Impact of Zn compounds on *Bradyrhizobium*–mungbean symbiosis was also unravelled. In this study, *Bradyrhizobium*–mungbean symbiosis was not affected at lower NPs concentrations. Therefore, these results could overcome the problem of Zn deficiency in edible parts of plants. nZnS treatment resulted in the overall improvement in growth, including yield. Therefore, there exists an opportunity for nZnS to use as a suitable alternative of commercially available bulk ionic salts for crop management at low concentration.

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