Plant Nanobiotechnology for Sustainable Agriculture

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Utilization of engineered nanoparticles (ENPs) in agriculture as fertilizers or pesticides requires cost-effective and efficient delivery methods to plant leaves and roots. We hypothesize that ENP properties like size, coating, charge, and dissolution rate can be selected to provide maximum delivery of ENPs or metallic species comprising them to selected locations in the plant vasculature. To evaluate the influence of NP size, charge, coating, and solubility on NP association and uptake by plant roots, we expose plants roots (hydroponic) or leaves (foliar spray) to NPs and then use synchrotron-based X-ray methods to provide spatially resolved metal distribution and speciation in order to understand the mechanisms of uptake. For solubility assessment, we exposed wheat seedlings hydroponically to 1 mg/L of Cu NPs with varying solubilities (CuO, CuS, and $Cu(OH)_2$). To evaluate the effect of ENP charge on their distribution in plant leaves, 4-nm CeO_2 particles with positive, negative, or neutral coatings were exposed hydroponically to roots at 10 mg/L under the same conditions, and allowed to translocate for up to 40h. To assess the effects of ENP size and coating on phloem loading and transport, Au NPs (5nm, 12m, and 50nm) with different coatings were drop-deposited on a leaf, and the resulting metal NP distribution was measured. In all cases, fresh, hydrated roots and leaves were analyzed using micro X-ray fluorescence (μ-XRF) and fluorescence X-ray absorption near edge spectroscopy (XANES) to provide laterally resolved spatial distribution and speciation of metal in plant tissues. High solubility $Cu(OH)_2$ NPs provided more Cu after 1 h of exposure, but the lower solubility materials (CuO and CuS) were more persistent over the 48h. Negatively charged particles translocated best to leaves, but had a different distribution in plant leaf tissue than the neutral particles. Positively charged particles did not translocate, but instead were stuck in the roots. The size and coating hydrophobicity of foliarly applied Au NPs affected their uptake and translocation, as well as the mechanisms of entry into the plant vasculature. These results improve our understanding mechanisms responsible for plant uptake, transformation, and translocation of ENPs, and suggest potential for engineering ENPs to be delivered to selected locations in plant tissues.