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Multimodal and multiresolution X-ray studies of nanoparticle pathways in plants.

Mineral nutrients are taken up by plants through their root network, therefore if additional nutrient is required, this is today applied to the soil in vast quantities. From this, the crops take up only a minor fraction [1]. We are researching the possibility to apply nutrients through foliar fertilization, developing nanoparticles (NPs) as vessels to deliver the fertilizer through the leaf into the plant. Our aim is to complement the traditional analytical methods such as laser ablation to determine the content of a certain element by X-ray based methods. We develop protocols for how to apply X-ray micro and nano-tomography, SAXS, and X-ray fluorescence to probe live and freeze-dried plants. Recent observations suggest that mineral nutrients (P, Mn, and Zn) delivered as nanoparticles (NPs) can enter the plant through the leaves and be delivered to the target location inside the plant. However, several instances of the NPs pathways rely on hypotheses rather than experimental evidence. For example, the role of stomata is significant, yet remains poorly understood [2]. Once inside the leaf, NPs must be able to enter the cells, and ideally also the vascular tissues (phloem), where transport to other parts of the plant occurs.

We have employed multiscale X-ray tomography using both lab and synchrotron-based radiation to visualize NP agglomeration and translocation as a function of both time and location in plant. In µCT (0.385 - 3 µm voxel size) MnO NPs applied to soy plants are visible as regions of contrast (seen as red in figure 1 a)) shortly after application and potential agglomerates in the vascular tissue a certain time after application. nCT (50 nm voxel size) measurements show high quality visualizations of the cellular structure of chloroplasts in the leaf and both xylem and phloem in the vascular tissue. Agglomerates (>0.5 µm) from NP solution drying on the leaf surface are visible, but no significant particle agglomerates are visible inside the plant structure. To support these measurements, we aim to do multimodal experiments employing SAXS and XRF in combination with tomography to obtain knowledge of NP behavior (transport, clustering, bioavailability, and dissolution) while having the 3D visualization capability of X-ray CT.

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