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Quantitative 3D elemental analysis inside plant roots by means of synchrotron confocal micro X-ray fluorescence

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The knowledge of the distribution and concentration of elements within plants is a fundamental step to better understand how these plants uptake specific elements from the medium of growth and how they manage acquisition and compartmentalisation of nutrients as well as toxic metals. For some elements, either nutrients or toxicants, it can be of relevance to know their concentration level within microscopic volumes in plant organs, where they are stored or accumulated. Usually, this type of microscopic analysis requires complex cutting procedures and extensive sample manipulations.
In this research, the technique of synchrotron micro X-ray fluorescence in the confocal mode was applied to image the distribution of elements in selected key-planes of tomato roots without the need of any sample preparation, except washing and freeze-drying. Using this method, a first polycapillary lens focussed the X-ray beam with an energy of 12.4 keV down to a 20 μm beam that is penetrating the sample, and a second polycapillary half-lens, that was positioned at the detection side at 90 degrees to the first polycapillary, could then restrict further the view on this irradiated volume to a defined microscopic volume (typically 20x20x20 μm3) from which the induced fluorescent radiation is finally collected by the energy dispersive detector. In this way, it was possible to investigate the concentration levels of some elements such as K, Ca, Mn, Fe, Cu and Zn within the roots of tomato plants.
The quantification was performed by means of a dedicated XRF Fundamental Parameter (FP) method in order to calculate the concentrations of trace elements within the analysed plants. Utilizing fundamental atomic parameters, the applied FP method is taking into account the influence of sample self-absorption and especially the specific detection processes by the polycapillary lens. Quantification was assessed and validated by using different standards: NIST SRM 1573a (trace elements in tomato leaves), NIST SRM 613 (trace elements in glass), and NIST SRM 1577b (trace elements in bovine liver). Accurate results could be obtained for Fe (within 2%), Cu and Zn (within 7%), and Mn (10%) while deviations ranging from 20 to 35% were observed for K and Ca, respectively. In particular, for an important nutrient such as Fe, concentration levels ranging from 370 μg g-1 down to 0.1 μg g-1 could be observed at different locations within the tomato roots.