Magnetic nanoparticles penetration and transport *in-planta*

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Magnetic nanoparticles are very suitable for a broad range of applications, like those involving synthesis and use of ferrofluids for bio-applications in general. In medicine the aim is to use them in diagnosis as well as in therapy. The ongoing research and results obtained up to now in these fields open a wide range of possibilities for using magnetic nanoparticles in other disciplines, for example in general plant research and agronomy. To study the use of nanoparticles in agriculture the first stage is to work out the penetration and transport into living plants and plant cells. We present here an overview of the research carried out within the scope of an interdisciplinary collaboration, on how inorganic nanoparticles interact with plant cells and tissues[1,2,3].

We have used iron/iron-oxides carbon-coated nanoparticles, synthesized by a gas-phase condensation method, in an arc-discharge furnace. Biocompatible suspensions of the nanoparticles have been synthesized and injected into pumpkin (*Cucurbita pepo*) living plants. The graphitic shell of our nanoparticles made possible their visualization into plant cells and tissues, using different microscopy techniques (fluorescence, confocal, light and electron microscopy). Moreover, their magnetic character allowed the nanoparticles to be positioned in the desired plant tissue by applying magnetic field gradients (produced by small permanent magnets). We have also observed that in the absence of magnetic fields, the nanoparticles can travel as well along the vascular systems, reaching different cell and tissues. Nanoparticles have been found both in the cytoplasm and in the extracellular space between cells. A size-based selection mechanism seems to be operating, probably involving cell walls and waxes acting as a barrier. With respect to cytotoxicity, it has been observed that cells containing nanoparticle agglomerates exhibited a cytoplasm denser than that of cells containing few nanoparticles. Damage at the plant level was not macroscopically evident.. However, further detailed studies are needed to evaluate the cytotoxicity and phytotoxicity of more intense treatments than those carried out in this study.
We have also studied the absorption and translocation of our nanoparticles into plants of different families (wheat, tomato, sunflower and pea) after their administration through the roots and by spraying the nanoparticles suspension on the leaves. It has been observed that nanoparticles reach the aerial part of the plant after 24 hours. In wheat plants accumulation of nanoparticles was detected in leaf trichomes, suggesting a way for nanoparticles excretion/detoxification.
Although more studies are necessary to unveil the nanoparticles penetration and translocation mechanisms as well as their cyto- and phyto-toxicity, our results open a wide range of possibilities for using magnetic nanoparticles in general plant research and agronomy.

References

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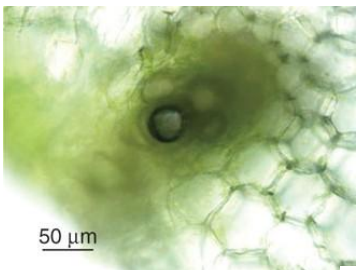
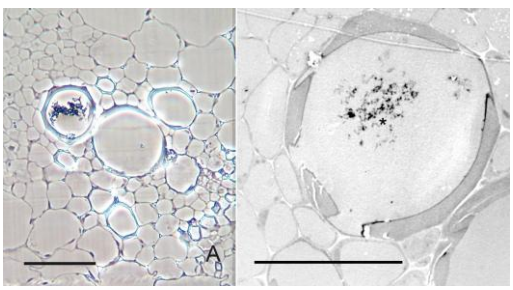
[2] E. Corredor et al., BMC Plant Biology **9** (2009) 45
[3] Z. Cifuentes et al., Journal of Nanobiotechnology (2010), **8**:26 doi: 10.1186/1477-3155-8-26



Light microscopy image of a petiole tissue at the magnet application point.



Nanoparticles inside xylem vessels: A) Phase contrast image B) TEM image of an ultrathin consecutive section. Bar: 30 µm