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A sustainable model for agriculture based on nanofibrous biodegradable polymers mimicking natural strategies

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ABSTRACT

The damage and risk to the environment and human health consequent to traditional agricultural practices urged the development of innovative techniques and more environmentally friendly processes and compounds. Nanotechnology can improve the precision in the processes and the coordination of the management strategies of agricultural production. Therefore, innovative and groundbreaking tools have recently been developed employing natural and engineered nanomaterials to deliver agrochemicals to plants for both improving nutrition, stimulate plant growth, improve the quality of the soil and protect plants, while reducing the impact of these compounds on the environment and human health. Electrospinning (ES) is a highly versatile and inexpensive nanotechnology that allows to design and fabricate continuous non-woven polymer fibers with diameters ranging from micrometer to nanometer when a strong electrical field acts on a droplet of a solution with sufficient viscoelasticity. The resulting fibers can assume complex shapes, creating a multitude of structures with a broad spectrum of different properties (porosity, permeability, high fiber interconnectivity, nano-scale interstitial spaces, biomimetism and bioinspiration, etc.).

Eco-compatible (biodegradable and biocompatible) nanofibrous smart fabrics with potentials in promoting plant growth

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Biostimulants

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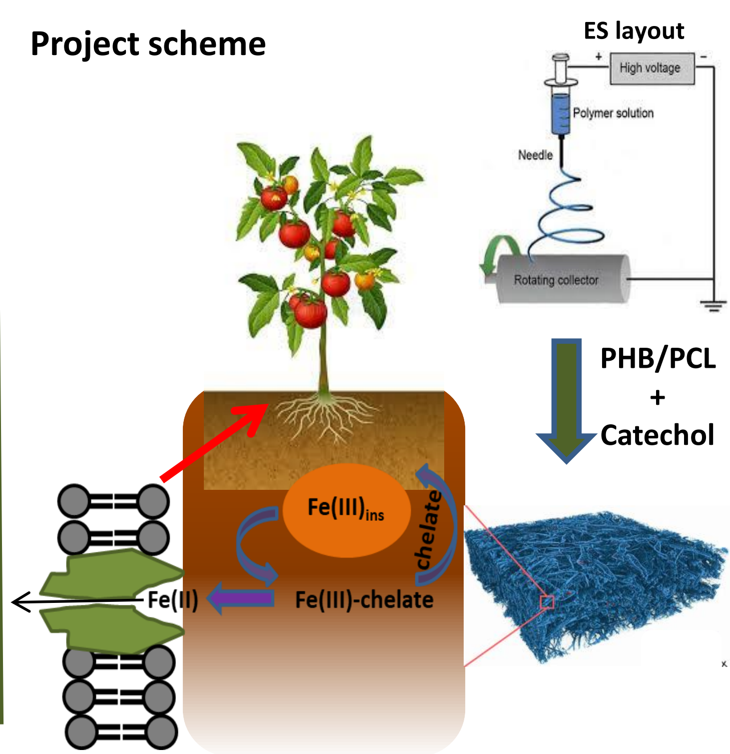
Nutrient-mobilizing molecules

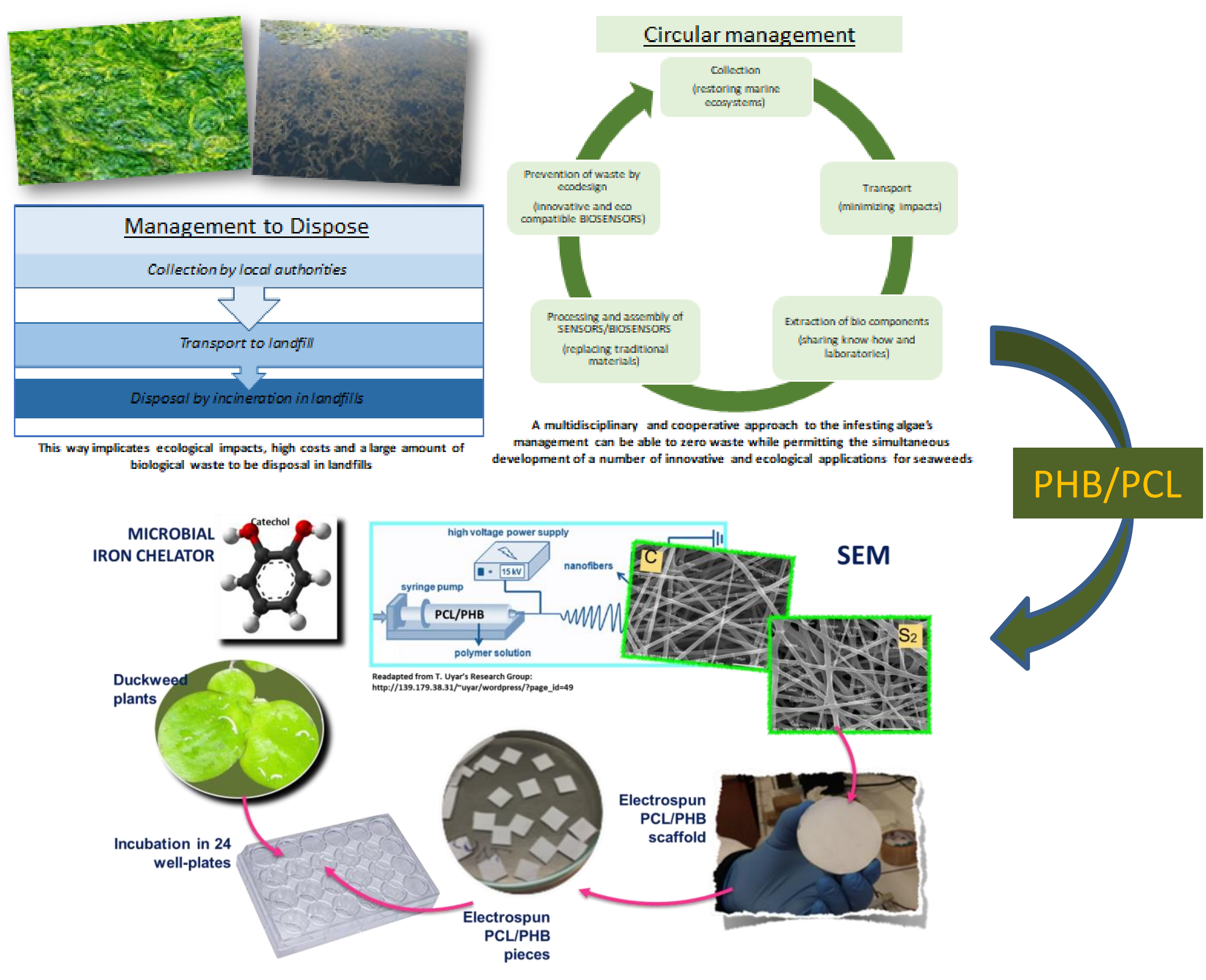
WORK NOVELTIES

- ✓ Engineering of nanofibrous textiles
- ✓ Eco-sustainable polymer fabrics
- ✓ Natural strategies mimicking protecting food and environment



Since the limitation of iron availability is a crucial condition in plant nutrition, the polymer fabrics here proposed, mimicking the natural strategy adopted by nongraminaceous and graminaceous species (Strategy I and II, respectively), were designed to make available to the plants the insoluble iron (Fe III) widely present in ecosystems by releasing selected iron-chelating molecules. Therefore, we investigated a model system based on ES biodegradable nanofibrous textiles with different shapes capable of releasing natural iron-chelators into soil/water by controlled rates (depending on the membrane morphology). The present study first focused on the production and functionality of a biodegradable nanofibrous polymer (polyhydroxybutyrate-PHB) scaffold, that is naturally produced by microorganisms and algae). Because of its fragility, PHB was then blended with another biodegradable polymer (polycaprolactone-PCL), and then properly bio-loaded. The resulting polymer blend, due to the physical properties of PCL, resulted softer and mechanically more resistant than the previous one (PHB) and it was poorly affected by sudden changes in temperature. Both polymers are water insoluble and present low environmental impact, and are commonly investigated and used in drug delivery structures. The effectiveness and toxicity of both functional systems mimicking Strategy I and II concepts and dynamics were tested in two different plant hydroponic cultures. Such regenerative and sustainable agricultural practices based on natural sources and waste reduction, inspired by the principles of a circular bio-economy (European Environment Agency, report n. 2/2016), aimed at replacing the use of chemicals and traditional raw materials, improving health and environmental conditions, as required by the original principles of a circular economy, and at facing the increasing risk level for our natural capital.

Infesting macro algae entail, especially in the Mediterranean Sea, heavy economic and ecological consequences.
It is essential to act to create a circular management for these kind of biomasses



Laboratory experiment

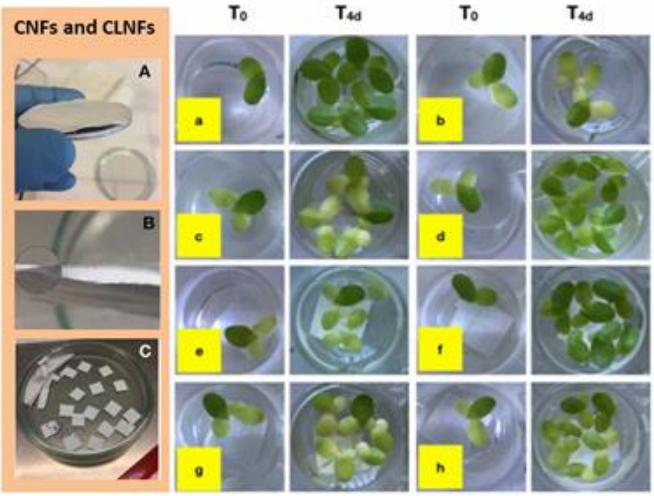
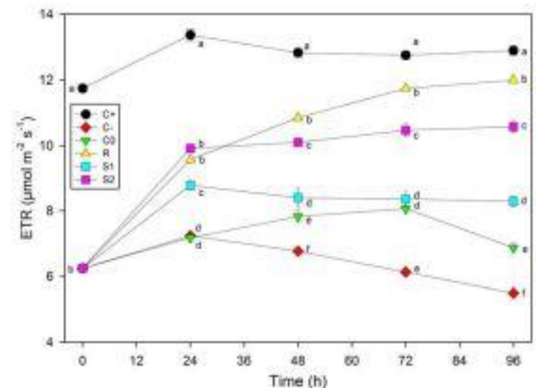
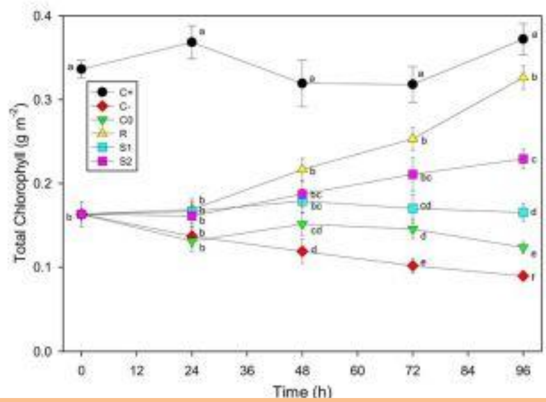


Figure 3.2.5. Electrospun nanomembranes (NMs) (irrespective of the catechol loading) after deposition onto the PEDOT-soaked paper attached to an aluminum disk (**A**); (**B**) NMs pealed off the mentioned supports; (**C**) NMs after cutting into 1 cm² pieces; Pictures of duckweeds fronds captured before (T_0) and after (T_{4d}) various treatments: **a)** C^+ = 6 μM Fe(EDTA) for both pre-treatment and treatment; **b)** C^- = no Fe for both pre-treatment and treatment; **c)** C_0 = no Fe (pre-treatment) + 6 μM $FeCl_3$; **d)** R = no Fe (pre-treatment) + 6 μM Fe(EDTA); **e)** T = no Fe for both pre-treatment and treatment + catechol-free nanomembranes (CNMs); **f)** A = 6 μM Fe(EDTA) for both pre-treatment and treatment + CNMs; **g)** C_1L-MNs = no Fe (pre-treatment) + 6 μM $FeCl_3$ + C1L-MNs (C_1 = 5 mM catechol); **h)** C_2L-MNs = no Fe (pre-treatment) 6 μM $FeCl_3$ + C_2L-MNs (C_2 = 100 mM catechol).

ELECTRON TRANSPORT RATE



CHLOROPHYLL



C+: Chlorophyll content showed almost unchanged values in control plants (C+) during incubation, while ΦPSII highlighted a slight increase after 24 h then keeping a constant values over the incubation period

C-: quantum efficiency of PSII (ΦPSII) decreased significantly indicating that the mechanisms of energy dissipation were engaged and depressed during the Fe deprivation period.

C0:both ΦPSII and chlorophyll content values at the end of the treatment resulted significantly higher than those of C^-

CONCLUSIONS & OUTLOOKS

The novelty of this study is that a natural strategy of iron nutrition typical of plants based on the release of organic Fe chelators was integrated with a nanofibrous fabric as the carrier of such bioactive natural molecules to mimic the release from the plant roots (mostly root hairs) of such Fe-mobilizing compounds aimed at providing Fe to plants.

Advantages: the use of eco-friendly biodegradable polymer materials as carriers could replace the plastic materials commonly used in the commercial slow-release fertilizers; the use of a natural Fe-chelating agent, such as catechol, could replace the use of synthetic chemicals thus reducing the global impact on the environment and health; the encapsulation of catechol molecules would prevent the leaching of Fe chelates and the possible pollution of water sources; catechol was aimed at mobilizing Fe from the natural insoluble sources present in the environment surrounding the plants (e.g., natural stocks in soil and sediments). Finally, the utilization of reusable organic chelating agents, like catechol (until degradation), that after Fe transfer to plant cells can be reused for the same activity and purpose thus making these nanofibers more efficient. In conclusion, electrospinning technology can be thought as a significant promoter of a new green revolution with reduced farming risks, low costs and smart managing.