Singapore's SMART researchers develop revolutionary Nanosensor for real-time iron detection in plants

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Singapore researchers have developed a near-infrared (NIR) fluorescent nanosensor capable of simultaneously detecting and differentiating between iron forms - Fe(II) and Fe(III) - in living plants. A ground-breaking innovation was developed by the Disruptive & Sustainable Technologies for Agricultural Precision (DiSTAP) interdisciplinary research group (IRG) at Singapore-MIT Alliance for Research and Technology (SMART), MIT's Singapore research enterprise. It was developed in collaboration with the Temasek Life Sciences Laboratory (TLL) and Massachusetts Institute of Technology (MIT).

Iron is crucial for plant health, supporting photosynthesis, respiration, and enzyme function. It primarily exists in two forms: Fe(II), which is readily available for plants to absorb and use, and Fe(III), which must first be converted into Fe(II) before plants can utilise it effectively. Traditional methods only measure total iron, missing the distinction between these forms â?? a key factor in plant nutrition. Distinguishing between Fe(II) and Fe(III) provides insights into iron uptake efficiency, helps diagnose deficiencies or toxicities, and enables precise fertilisation strategies in agriculture, reducing waste and environmental impact while improving crop productivity.

This first-of-its-kind nanosensor by SMART researchers enables real-time, non-destructive monitoring of iron uptake, transport, and changes between its different forms, such as Fe(II) and Fe(III)**â??** providing precise and detailed observations of iron dynamics. Its high spatial resolution allows precise localisation of iron in plant tissues or subcellular compartments, enabling the measuring of even minute changes in iron levels within plants - these minute changes can inform how a plant handles stress and uses nutrients.

Traditional detection methods are destructive or limited to a single form of iron. This new technology enables the diagnosis of deficiencies and optimisation of fertilisation strategies. By identifying insufficient or excessive iron intake, adjustments can be made to enhance plant health, reduce waste, and support more sustainable agriculture. While the nanosensor was tested on spinach and bok choy, it is species-agnostic, allowing it to be applied across a diverse range of plant species without genetic modification. This capability enhances our understanding of iron dynamics in various ecological settings, providing comprehensive insights into plant health and nutrient management. As a result, it serves as a valuable tool for both fundamental plant research and agricultural applications, supporting precision nutrient management, reducing fertiliser waste, and improving crop health.

â??Iron is essential for plant growth and development, but monitoring its levels in plants has been a challenge. This breakthrough sensor is the first of its kind to detect both Fe(II) and Fe(III) in living plants with real-time, high-resolution imaging. With this technology, we can ensure plants receive the right amount of iron, improving crop health and agricultural sustainability,â?• said Dr Duc Thinh Khong, DiSTAP research scientist and co-lead author of the paper.

â??In enabling non-destructive real-time tracking of iron speciation in plants, this sensor opens new avenues for understanding plant iron metabolism and the implications of different iron variations for plants. Such knowledge will help guide the development of tailored management approaches to improve crop yield and more cost-effective soil fertilisation strategies,â?• said **Dr Grace Tan, TLL Research Scientist.**

The new nanosensor features single-walled carbon nanotubes (SWNTs) wrapped in a negatively charged fluorescent polymer, forming a helical corona phase structure that interacts differently with Fe(II) and Fe(III). Upon introduction into plant tissues and interaction with iron, the sensor emits distinct NIR fluorescence signals based on the iron type, enabling real-time tracking of iron movement and chemical changes.