SMART
Singapore-MIT Alliance for Research and Technology

Novel Analytical tools developed by SMART key to Next-generation Agriculture

Next-gen analytical technologies will enable sustainable practices in traditional and urban agriculture

- Plant nanosensors and Raman spectroscopy are two emerging analytical technologies and tools to study plants and monitor plant health, enabling research opportunities in plant science that have so far been difficult to achieve with conventional technologies such as genetic engineering techniques
- The species-independent analytical tools are rapid and non-destructive, overcoming current limitations and providing a wealth of real-time information, such as early plant stress detection and hormonal signalling, that are important to plant growth and yield
- Perspective study evaluates further development of the tools, their economic potential and discusses implementation strategies for successful integration in future farming practices for traditional and urban agriculture

Singapore, 10 February 2021 - Researchers from the Disruptive & Sustainable Technologies for Agricultural Precision (DiSTAP) Interdisciplinary Research Group (IRG) of Singapore-MIT Alliance for Research and Technology (SMART), MIT's research enterprise in Singapore, and Temasek Life Sciences Laboratory (TLL), highlight the potential of recently developed analytical tools that are rapid and non-destructive, with a proof of concept through first-generation examples. The analytical tools are able to provide tissue-cell or organelle-specific information on living plants in real-time and can be used on any plant species.

In a perspective paper titled "Species-independent analytical tools for next-generation agriculture" published in the scientific journal *Nature Plants*, SMART DiSTAP researchers review the development of two next-generation tools, engineered plant nanosensors and portable Raman spectroscopy, to detect biotic and abiotic stress, monitor plant hormonal signalling, and characterise soil, phytobiome and crop health in a non- or minimally invasive manner. The researchers discussed how the tools bridge the gap between model plants in the laboratory and field application for agriculturally relevant plants. An assessment of the future outlook, economic potential, and implementation strategies for the integration of these technologies in future farming practices was also provided in the paper.

According to UN estimates, the global population is expected to grow by 2 billion within the next 30 years, giving rise to an expected increase in demand for food and agricultural products to feed the growing population. Today, biotic and abiotic environmental stresses such as plant pathogens, sudden fluctuations in temperature, drought, soil salinity, and toxic metal pollution - made worse by climate change - impair crop productivity and lead to significant losses in agriculture yield worldwide.

An estimated 11-30% yield loss of five major crops of global importance (wheat, rice maize, potato, and soybean) are caused by crop pathogens and insects; with the highest crop losses observed in regions already suffering from food insecurity. Against this backdrop, research into innovative technologies and tools are required for sustainable agricultural practices and meet the rising demand for food and food security - an issue that has drawn the attention of governments worldwide due to the COVID-19 pandemic.

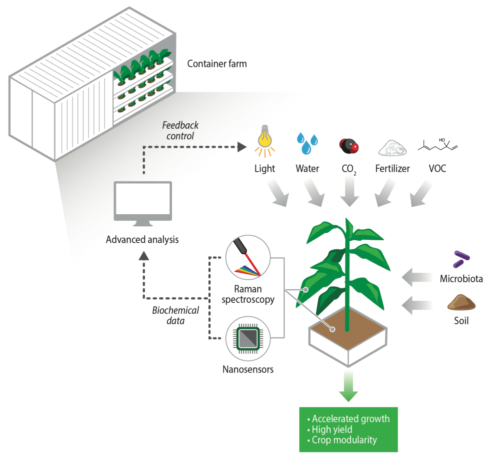
Plant nanosensors, developed at SMART DiSTAP, are small nanosensors - smaller than the width of a hair - that can be inserted into the tissues and cells of plants to understand complex signalling pathways. The portable Raman spectroscopy, also developed at SMART DiSTAP, is a portable laser-based device that measures molecular vibrations induced by laser excitation, providing highly specific Raman spectral signatures that provide a fingerprint of a plant's health. These tools are able to monitor stress signals in short time-scales, ranging from seconds to minutes, which allow for early detection of stress signals in real-time.

"The use of plant nanosensors and Raman spectroscopy has the potential to advance our understanding of crop health, behaviour, and dynamics in agricultural settings," said Dr Tedrick Thomas Salim Lew, the paper's first author and a recent graduate student of the Massachusetts Institute of Technology (MIT). "Plants are highly complex machines within a dynamic ecosystem, and a fundamental study of its internal workings and diverse microbial communities of its ecosystem is important to uncover meaningful information that will be helpful to farmers and enable sustainable farming practices. These next-generation tools can help answer a key challenge in plant biology, which is to bridge the knowledge gap between our understanding of model laboratory-grown plants and agriculturally-relevant crops cultivated in fields or production facilities."

Early plant stress detection is key to timely intervention and increasing the effectiveness of management decisions for specific types of stress conditions in plants. The development of these tools capable of studying plant health and reporting stress events in real-time will benefit both plant biologists and farmers. The data obtained from these tools can be translated into useful information for farmers to make management decisions in real-time to prevent yield loss and reduced crop quality.

The species-independent tools also offer new study opportunities in plant science for researchers. In contrast to conventional genetic engineering techniques that are only applicable to model plants in laboratory settings, the new tools apply to any plant species which enables the study of agriculturally-relevant crops previously understudied. The adoption of these tools can enhance researchers' basic understanding of plant science and potentially bridge the gap between model and non-model plants.

"The SMART DiSTAP interdisciplinary team facilitated the work for this paper and we have both experts in engineering new agriculture technologies and potential end-users of these technologies involved in the evaluation process," said Professor Michael Strano, the paper's co-corresponding author, DiSTAP co-lead Principal Investigator, and Carbon P. Dubbs Professor of Chemical Engineering at MIT. "It has been the dream of an urban farmer to continually, at all times, engineer optimal growth conditions for plants with precise inputs and tightly controlled variables. These tools open the possibility of real-time feedback control schemes that will accelerate and improve plant growth, yield, nutrition, and culinary properties by providing optimal growth conditions for plants in the future of urban farming."



Species-independent analytical platforms can facilitate the creation of feedback-controlled high-density agriculture.
Photo Credit: Betsy Skrip, Massachusetts Institute of Technology

"To facilitate widespread adoption of these technologies in agriculture, we have to validate their economic potential and reliability, ensuring that they remain cost-efficient and more effective than existing approaches," the paper's co-corresponding author, DiSTAP co-lead Principal Investigator, and Deputy Chairman of TLL Professor Chua Nam Hai explained. "Plant nanosensors and Raman spectroscopy would allow farmers to adjust fertiliser and water usage, based on internal responses within the plant, to optimise growth, driving cost efficiencies in resource utilisation. Optimal harvesting conditions may also translate into higher revenue from increased product quality that customers are willing to pay a premium for."

Collaboration among engineers, plant biologists, and data scientists, and further testing of new tools under field conditions with critical evaluations of their technical robustness and economic potential will be important in ensuring sustainable implementation of technologies in tomorrow's agriculture.

DiSTAP Scientific Advisory Board Members, Professor Kazuki Saito, Group Director of Metabolomics Research Group at RIKEN Center for Sustainable Resource Science, and Hebrew University of Jerusalem Professor, Oded Shoseyov also co-authored the paper.

The research is carried out by SMART and supported by the National Research Foundation (NRF) Singapore under its Campus for Research Excellence And Technological Enterprise (CREATE) programme.

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About SMART Disruptive & Sustainable Technologies for Agricultural Precision (DiSTAP) [精准农业技术研究中心]

DiSTAP is one of the five Interdisciplinary Research Groups (IRGs) of the Singapore-MIT Alliance for Research and Technology (SMART). The DiSTAP programme addresses deep problems in food production in Singapore and the world by developing a suite of impactful and novel analytical, genetic and biosynthetic technologies. The goal is to fundamentally change how plant biosynthetic pathways are discovered, monitored, engineered and ultimately translated to meet the global demand for food and nutrients. Scientists from Massachusetts Institute of Technology (MIT), Temasek Life Sciences Laboratory (TLL), Nanyang Technological University (NTU) and National University of Singapore (NUS) are collaboratively: developing new tools for the continuous measurement of important plant metabolites and hormones for novel discovery, deeper understanding and control of plant biosynthetic pathways in ways not yet possible, especially in the context of green leafy vegetables; leveraging these new techniques to engineer plants with highly desirable properties for global food security, including high yield density production, drought and pathogen resistance and biosynthesis of high-value commercial products; developing tools for producing hydrophobic food components in industry-relevant microbes; developing novel microbial and enzymatic technologies to produce volatile organic compounds that can protect and/or promote growth of leafy vegetables; and applying these technologies to improve urban farming.

The DiSTAP IRG at SMART is led by MIT co-lead Principal Investigator Professor Michael Strano and Singapore co-lead Principal Investigator Professor Chua Nam Hai.

For more information, please log on to: http://distap.mit.edu/

About Singapore-MIT Alliance for Research and Technology (SMART) [新加坡-麻省理工学院科研中心]

Singapore-MIT Alliance for Research and Technology (SMART) is MIT's Research Enterprise in Singapore, established by the Massachusetts Institute of Technology (MIT) in partnership with the National Research Foundation of Singapore (NRF) since 2007. SMART is the first entity in the Campus for Research Excellence and Technological Enterprise (CREATE) developed by NRF. SMART serves as an intellectual and innovation hub for research interactions between MIT and Singapore. Cutting-edge research projects in areas of interest to both Singapore and MIT are undertaken at SMART. SMART currently comprises an Innovation Centre and five Interdisciplinary Research Groups (IRGs): Antimicrobial Resistance (AMR), Critical Analytics for Manufacturing Personalized-Medicine (CAMP), Disruptive & Sustainable Technologies for Agricultural Precision (DiSTAP), Future Urban Mobility (FM) and Low Energy Electronic Systems (LEES).

SMART research is funded by the National Research Foundation Singapore under the CREATE programme. For more information, please visit - http://smart.mit.edu

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