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Nanobionic spinach plants can detect explosives

31 October 2016

Spinach is no longer just a superfood: By embedding leaves with carbon nanotubes, MIT engineers have transformed spinach plants into sensors that can detect explosives and wirelessly relay that information to a handheld device similar to a smartphone.

This is one of the first demonstrations of engineering electronic systems into plants, an approach that the researchers call "plant nanobionics."

"The goal of plant nanobionics is to introduce nanoparticles into the plant to give it non-native functions," says Michael Strano, the Carbon P. Dubbs Professor of Chemical Engineering at MIT and the leader of the research team.

In this case, the plants were designed to detect chemical compounds known as nitroaromatics, which are often used in landmines and other explosives. When one of these chemicals is present in the groundwater sampled naturally by the plant, carbon nanotubes embedded in the plant leaves emit a fluorescent signal that can be read with an infrared camera. The camera can be attached to a small computer similar to a smartphone, which then sends an email to the user.

"This is a novel demonstration of how we have overcome the plant/human communication barrier," says Strano, who believes plant power could also be harnessed to warn of pollutants and environmental conditions such as drought.

Strano is the senior author of a paper describing the nanobionic plants in the Oct. 31 issue of *Nature Materials*. The paper's lead author is Min Hao Wong, an MIT graduate student who has started a company called Plantea to further develop this technology.

Environmental monitoring

Two years ago, in the first demonstration of plant nanobionics, Strano and former MIT postdoc Juan Pablo Giraldo used nanoparticles to enhance plants' photosynthesis ability and to turn them into sensors for nitric oxide, a pollutant produced by combustion.

Plants are ideally suited for monitoring the environment because they already take in a lot of information from their surroundings, Strano says.

"Plants are very good analytical chemists," he says. "They have an extensive root network in the soil, are constantly sampling groundwater, and have a way to self-power the transport of that water up into the leaves."

Strano's lab has previously developed carbon nanotubes that can be used as sensors to detect a wide range of molecules, including hydrogen peroxide, the explosive TNT, and the nerve gas sarin. When the target molecule binds to a polymer wrapped around the nanotube, it alters the tube's fluorescence.

In the new study, the researchers embedded sensors for nitroaromatic compounds into the leaves of spinach plants. Using a technique called vascular infusion, which involves applying a solution of nanoparticles to the underside of the leaf, they placed the sensors into a leaf layer known as the mesophyll, which is where most photosynthesis takes place.

They also embedded carbon nanotubes that emit a constant fluorescent signal that serves as a reference. This allows the researchers to compare the two fluorescent signals, making it easier to determine if the explosive sensor has detected anything. If there are any explosive molecules in the groundwater, it takes about 10 minutes for the plant to draw them up into the leaves, where they encounter the detector.

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To read the signal, the researchers shine a laser onto the leaf, prompting the nanotubes in the leaf to emit near-infrared fluorescent light. This can be detected with a small infrared camera connected to a Raspberry Pi, a $35 credit-card-sized computer similar to the computer inside a smartphone. The signal could also be detected with a smartphone by removing the infrared filter that most camera phones have, the researchers say.

"This setup could be replaced by a cell phone and the right kind of camera," Strano says. "It's just the infrared filter that would stop you from using your cell phone."

Using this setup, the researchers can pick up a signal from about 1 meter away from the plant, and they are now working on increasing that distance.

"A wealth of information"

In the 2014 plant nanobionics study, Strano's lab worked with a common laboratory plant known as Arabidopsis thaliana. However, the researchers wanted to use common spinach plants for the latest study, to demonstrate the versatility of this technique. "You can apply these techniques with any living plant," Strano says.

So far, the researchers have also engineered spinach plants that can detect dopamine, which influences plant root growth, and they are now working on additional sensors, including some that track the chemicals plants use to convey information within their own tissues.

"Plants are very environmentally responsive," Strano says. "They know that there is going to be a drought long before we do. They can detect small changes in the properties of soil and water potential. If we tap into those chemical signaling pathways, there is a wealth of information to access."

These sensors could also help botanists learn more about the inner workings of plants, monitor plant health, and maximize the yield of rare compounds synthesized by plants such as the Madagascar periwinkle, which produces drugs used to treat cancer.

"These sensors give real-time information from the plant. It is almost like having the plant talk to us about the environment they are in," Wong says. "In the case of precision agriculture, having such information can directly affect yield and margins."

More information: Nitroaromatic detection and infrared communication from wild-type plants using plant nanobionics, *Nature Materials*, DOI: 10.1038/nmat4771

Provided by Massachusetts Institute of Technology