Scientists reveal secrets of drought resistance

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A team of biologists in California led by researchers at The Scripps Research Institute and the University of California, San Diego has solved the structure of a critical molecule that helps plants survive during droughts. Understanding the inner workings of this molecule may help scientists design new ways to protect crops against prolonged dry periods, potentially improving crop yields worldwide, aiding biofuels production on marginal lands and mitigating drought's human and economic costs.

The findings were described in the journal *Science Express,* an advance online issue of *Science*, on October 22, 2009.

"This molecular structure helps explain the mechanism behind drought tolerance in plants," said Elizabeth Getzoff, a Scripps Research scientist who led the team from Scripps Research, UC San Diego, Lawrence Berkeley National Laboratory, and UC Riverside. "We're very excited by the findings."

According to the National Oceanic and Atmospheric Administration, major droughts in the last three years alone have collectively caused more than ten billion dollars in losses to crops and other damages in the United States. The problem is particularly pronounced in western farm areas such as those in California, which is now three years into a severe drought.

The newly solved structure shows a three-dimensional representation of a critical plant hormone called abscisic acid, attached to its "target" protein called PYR1. Abscisic acid is key to many plant processes, including to survival tactics in challenging environmental conditions.

"In revealing how a plant hormone functions under stressful conditions, this work provides important clues about how hormones might regulate crucial physiological responses in humans," said Jean Chin, a program director with the National Institutes of Health's National Institute of General Medical Sciences.

A Mysterious Hormone

When drought-tolerant plants detect dry conditions, they synthesize abscisic acid, which causes changes from root tips to leaves and flowers. Plants under the influence of this hormone begin to conserve water. Their seeds lie dormant in the ground. Their leaves close microscopic pores to stop water loss. They slow their own growth, and they signal numerous genetic changes, reprogramming themselves to accomplish their single most pressing goal - survival.

"Abscisic acid triggers an array of plant drought-tolerance mechanisms," said co-investigator Julian Schroeder of UC San Diego.

The hormone abscisic acid was discovered in the early 1960s, and plant biologists have known for decades that it plays this crucial role in keeping plants alive during drought. Despite this fact, says Getzoff, who is a professor in the Department of Molecular Biology and The Skaggs Institute for Chemical Biology at Scripps Research, nobody has understood how the hormone functions.

"That has been pretty mysterious," Getzoff says, "yet solving this mystery is key to controlling drought responses to protect plants."

Earlier this year, however, the picture of how abscisic acid works became clearer when two separate groups of scientists discovered a cluster of genes associated with the hormone. Simultaneous mutations in four of these related genes led to a greatly impaired abscisic acid response and reduced drought resistance. Scientists suspected it was because the genes produced proteins that are normally targets of the hormone — an association that the mutations disrupted. One of the groups was a team of researchers led by Sean Cutler of UC Riverside, whose initial work on the protein PYR1 led to the current study.

"This early research with Sean led to important new questions," said Schroeder, who together with Getzoff initiated the current study. "We wanted to know if abscisic acid bound specifically to the PYR1 protein as a hormone receptor or whether it acted like a glue between PYR1 and partner proteins."

Structure Revealed

Collaborating closely with Schroeder and his lab, Getzoff and her group decided to try to figure out exactly how PYR1 was involved in drought resistance by looking at PYR1 and abscisic acid molecules on the micro-and nano-scales.

"Team researchers Noriyuki Nishimura of UC San Diego, Kenichi Hitomi, Andrew Arvai, and Chiharu Hitomi of Scripps Research, and Robert Rambo of Lawrence Berkeley National Laboratory used a multi-disciplinary attack to overcome challenges in characterizing the abscisic acid sensor and to decipher its mechanism," said Getzoff.

First, Getzoff's lab enlisted the use of a technique called x-ray crystallography. X-ray crystallography is a method that can determine three-dimensional positions for the individual atoms of a protein's structure. To make the technique work, scientists manipulate a protein or some other molecule so that a crystal forms, which is often extremely difficult. If the scientists are successful in making a crystal, it is then placed in front of a beam of x-rays, which diffract when they strike the crystal's atoms. Based on the pattern of diffraction, scientists can reconstruct the shape of the original molecule.

In this case, the team tried to make crystals of PYR1 bound to abscisic acid. They succeeded and were able to solve and analyze the structure.

In addition, Schroeder's lab studied the association of these molecules inside living plant cells. And Rambo did complementary structural studies with x-rays to look at how the binding of hormone to PYR1 caused the protein to change shape in solution.

The research showed that two copies of PYR1 fit snugly together in plant cells. There, they are targeted by abscisic acid. Each copy of the PYR1 molecule has an internal open space like the inside of a tin can, and when a hormone molecule comes along, it fits neatly into one of the two spaces. This induces part of the PYR1 protein that the team calls the "lid" to close. Further structural changes to other parts of the PYR1 molecule initiate interactions with other proteins thus triggering plant processes for resisting drought.

Tantalizing Possibilities

The structure may reveal new ways of improving drought tolerance in plants, notes Getzoff. Such improvements would be a boon for agriculture, which is the single largest use for water in most of the world, consuming up to 90 percent of available water in some of the hottest and most arid parts of the world, which are often prone to drought.

One possible way to translate this research to agricultural products, says Getzoff, would be to design chemicals to mimic the action of abscisic acid. Such chemicals would then be sprayed on crops to protect them in the face of looming drought. The hormone itself would not work for this purpose because industrial-scale production of abscisic acid would be very expensive and sunlight can convert it into an inactive form. Getzoff cautions, however, it would likely take years before such substances were ready for widespread commercial use. Schroeder adds that understanding the structure of the abscisic acid binding site could conceivably help in redesigning the receptor itself to be bound and activated by known cheap and environmentally safe chemicals. That could be a future boon to agriculture.

More information: The article, "Structural Mechanism of Abscisic Acid Binding and Signaling by Dimeric PYR1," has four co-first authors Nishimura, Hitomi, Arvai, and Rambo, emphasizing the teamwork involved.
More information on drought in the United States is available at: www.drought.gov/portal/server. … nity/drought_gov/202 .

Source: The Scripps Research Institute (news :

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