Gene That Controls Ozone Resistance of Plants Could Lead to Drought-Resistant Crops

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Biologists at the University of California, San Diego, working with collaborators at the University of Helsinki in Finland and two other European institutions, have elucidated the mechanism of a plant gene that controls the amount of atmospheric ozone entering a plant's leaves.

Their finding helps explain why rising concentrations of carbon dioxide in the atmosphere may not necessarily lead to greater photosynthetic activity and carbon sequestration by plants as atmospheric ozone pollutants increase. And it provides a new tool for geneticists to design plants with an ability to resist droughts by regulating the opening and closing of their stomata-the tiny breathing pores in leaves through which gases and water vapor flow during photosynthesis and respiration.

"Droughts, elevated ozone levels and other environmental stresses can impact crop yields," said Jean Chin, who oversees membrane protein grants at the National Institute of General Medical Sciences, which partially funded the research. "This work gives us a clearer picture of how plants respond to these kinds of stresses and could lead to new ways to increase their resistance."

The discovery is detailed in this week's advance online publication of the journal *Nature* by biologists at UCSD, University of Helsinki in Finland, University of Tartu in Estonia and the University of the West of England. Last year, the journal published another study by British researchers that found that ozone generated from the nitrogen oxides of vehicle emissions would significantly reduce the ability of plants to increase photosynthesis and store the excess carbon in the atmosphere projected from rising levels of carbon dioxide.

"When ozone enters the leaf through the stomatal pores, it damages the plants photosynthetic machinery and basically causes green leaves to lose their color, a process called chlorosis," said Julian Schroeder, a professor of biological sciences at UC San Diego and one of the principal authors of the recent study. "Plants have a way to protect themselves and they do that by closing the stomatal pores when concentrations of ozone increase."

While this protective mechanism minimizes the damage to plants, he adds, it also minimizes their ability to photosynthesize when ozone levels are high, because the stomatal pores are also the breathing holes in leaves through which carbon dioxide enters leaves. The result is diminished plant growth or at least less than one might expect given the rising levels of carbon dioxide.

Some scientists assessing the impacts of rising greenhouse gases had initially estimated that increased plant growth generated from extra carbon dioxide in the atmosphere could sequester much of the excess atmospheric carbon in plant material. But in a paper published last July in *Nature*, researchers from Britain's Hadley Centre for Climate Prediction and Research concluded that the damage done to plants by increasing ozone pollution would actually reduce the ability of plants to soak up carbon from the atmosphere by 15 percent which corresponds to about 30 billion tons of carbon per year on a global scale---a dire prediction given that humans are already putting more carbon into the atmosphere than plants can soak up.

The discovery of the ozone-responsive plant gene was made when Jaakko Kangasjarvi and his collaborators at the University of Helsinki in Finland found a mutant form of the common mustard plant, *Arabidopsis,* that was extremely sensitive to ozone. They next found that this mutant does not close its stomatal pores in response to ozone stress.

"When the mutant plant is exposed to ozone, the leaves lose their dark green color and eventually become white," said Kangasjarvi, who is also one of the principal authors of the study. "This is because the stomatal pores in the leaves stay open even in the presence of high ozone and are unable to protect the plant."

The scientists found that the gene responsible for the mutation is essential for the function of what they called a "slow or S-type anion channel." Anions are negatively charged ions and these particular anion channels are located within specialized cells called guard cells that surround the stomatal pores. The gene was therefore named *SLAC1* for "slow anion channel 1."

Guard cells close stomatal pores in the event of excess ozone or drought. When this gene is absent or defective, the mutant plant fails to close its stomatal pores.

In 1989, Schroeder discovered these slow anion channels in guard cells by electrical recordings from guard cells using tiny micro-electrodes. He predicted that these anion channels would be important for closing the stomatal breathing pores in leaves under drought stress.

"The model we proposed back then was that the anion channels are a kind of electrical tire valve in guard cells, because our studies suggested that closing stomatal pores requires a type of electrically controlled deflation of the guard cells," he said. "But finding the gene responsible for the anion channels has eluded many researchers since then."

The latest study shows that the *SLAC1* gene encodes a membrane protein that is essential for the function of these anion channels. "We analyzed a lot of mechanisms in the guard cells and, in the end, the slow anion channels were what was missing in the mutant," said Yongfei Wang, a post doctoral associate in Schroeder's lab and co-first author of the paper.

The scientists showed that the *SLAC1* gene is required for stomatal closing to various stresses, including ozone and the plant hormone abscisic acid, which controls stomatal closing in response to drought stress. Elevated carbon dioxide in the atmosphere also causes a partial closing of stomatal pores in leaves. By contrast, the scientists found, the mutant gene does not close the plants' stomatal pores when carbon dioxide levels are elevated.

"We now finally have genetic evidence for the electric tire valve model and the gene to work with," said Schroeder.

Because the opening and closing of stomatal pores also regulates water loss from plants, Schroeder said, understanding the genetic and biochemical mechanisms that control the guard cells during closing of the stomatal pores in response to stress can have important applications for agricultural scientists seeking to genetically engineer crops and other plants capable of withstanding severe droughts.

"Plants under drought stress will lose 95 percent of their water through evaporation through stomatal pores, and the anion channel is a central control mechanism that mediates stomatal closing, which reduces plant water loss," he said.

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