

Science Notes
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Dry Fields with Great Yields
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When the Dust Bowl comes back to the western United States, will drought-resistant crops help the thirsty land?

The orange lights in the greenhouse glow like artificial suns. Tobacco plants reach toward them in the still, humid air. Their pale pink trumpet flowers and dark leaves hide a secret. Some scientists call them chimeras, after the mythical monster with the heads of a goat, lion, and snake; their DNA is part tobacco, part bean, and part bacterium. The strange genes have given the plants a superpower: drought resistance.

Scientists have devised these “transgenic” plants to fight the formidable foe of water shortages, caused by climate change. These plants drink two-thirds less water than average tobacco. Crops like canola, tomatoes, cotton, and rice may soon share their hardiness. The balmy greenhouse where these chimeras grow is a training ground for the global greenhouse their descendants will inhabit, under the open sky.

As temperatures rise, many climate models predict another Dust Bowl. This historic 1930s drought may come back to haunt the American West in three decades or less. Rivers that cut through the arid land like vital arteries will shrink. More rain and less snow will fall onto the Sierra Nevada. Some precious precipitation will evaporate too early to make it down, and states that depend on it will suffer, unless agriculture adapts quickly. But engineering crops takes time.

“To do transgenic plants is not. . . poof!” says plant biologist Eduardo Blumwald with his strong Argentinean accent, flicking his wrist like a magician. Blumwald hopes his crops will come to the fields in time to battle drought and famine. “Today, today, 2008, I think there is enough food in the world.” He taps the desk with one finger. “But in another ten, fifteen, twenty years, I don’t think so.”

That’s one reason post-doctoral researcher Rosa Rivero spends 10 to 11 hours a day—and sometimes weekends too—in Blumwald’s lab at the University of California, Davis. She’s examining the molecular mechanisms that keep the tobacco going on 70 percent less water. Many scientists have proposed methods to make water-saving plants, but Blumwald and Rivero are the first to do it so well. Their transgenic plants don’t drop their leaves and shrivel in tough times; they wilt a bit and perk up again when watered. Blumwald’s work is partially funded by a Davis-based biotechnology firm, Arcadia Biosciences, that is trying to validate these results and work toward federal approval.

But some consumer advocates think these chimeras must be caged. They say transgenic foods get scant safety testing on the way to grocery stores, and they can sicken or even kill laboratory animals. Biotechnology companies and some scientists contend these concerns aren’t based on firm evidence. The impending drought, on the other hand, looms as clearly as the Sierra.

Dire, drier predictions

“The whole surface of the planet is warming up,” says climate scientist Richard Seager of Columbia University’s Lamont-Doherty Earth Observatory. “There will be year-to-year variability, but all under a gradual drying trend.” Seager, who has examined past North American droughts, recently published a study on the return of the western Dust Bowl. He studied 19 climate models, and 18 of them agree: Drought maps depicting water shortages in the western U.S. in yellows, oranges, and parched reds will only get redder.

For states like Arizona, Utah, New Mexico, Nevada, and California, keeping things green is already difficult. California, the biggest water guzzler, usually pours more than 80 percent of its water into agriculture; it used 30.5 billion gallons for irrigation in 2000. Other southwestern states use less, but they all depend on rivers like the Colorado. Scientists studying the Colorado think that in two decades, it won’t be able to slake that thirst. Snow on the Sierra will melt more quickly, and that water will gush down the slopes two weeks earlier in the spring by 2050. Some will evaporate before the water infrastructure can collect it. A single wet winter won’t alter this long-term trend, Seager says: “It’s time to start planning for this.”

Promoting good behavior

People have weathered droughts by altering crops in the past, but not by using DNA chimeras. During the original Dust Bowl, before anyone used the term “gene” or knew that these little snippets of DNA control a living thing’s biochemistry, researchers bred more resilient and productive corn by moving pollen between cornstalks and controlling mating. This corn survived dry weather that often killed other varieties. Today, armies of it cover U.S. fields.

No one toyed with DNA directly until 1973, two decades after James Watson and Francis Crick described its twisting ladder shape. Researchers learned that certain proteins would snip DNA and others would stitch it together. They handcrafted genes and put them into bacteria. Bacteria have since become genetic engineers’ little helpers, because some will infect plants, delivering the new genes. Scientists kill the bacteria with antibiotics directly afterward, leaving added genes that can control many of the plants’ traits by telling them which proteins to build.

Scientists engineering plants are like painters using palettes with thousands of colors. Of all the genes out there, which ones to choose? Researchers demonstrated in 1995 that a gene for making extra cytokinin—the hormone that helps a plant retain its leaves—would keep plants not only green during drought, but fruitful. Leaves make the sugars and starches that plants store in their fruits and seeds, using carbon dioxide and sunlight.

During droughts, plants naturally drop leaves and favor roots, a strategy at odds with agriculture. Plants in the wild just want to live on through their kids, Blumwald says. “Even if they drop eighty percent of the leaves but can make a few seeds that will be blown away and grow somewhere, heck, that’s evolution.” But he says we’ve bred crops that go all or nothing; they make lots of grains or kernels, but they can’t scale back in dry times. Scientists thought that if these crops made more cytokinin and kept their leaves, we’d have amber waves of grain that could stand searing waves of heat.

The challenge, Blumwald says, was finding a "promoter," a second snippet of DNA that would make the cytokinin gene really step it up during drought. The 1995 study tried a promoter that turned on the cytokinin machinery when leaves started dying. However, this meant that even during wetter times, old leaves would stay vivacious. Later studies found that these leaves could steal resources from younger tissue. The lead author of the 1995 study, plant biologist Susheng Gan of Cornell University, believes his plants only had problems because they were given restricted resources during the experiments. With more nutrients, he says, the young tissue would do fine. But no one has tested his theory. Instead of this potentially problematic promoter, Blumwald wanted one that switched on only when drought stressed the plants.

Tiny puzzle pieces

Luckily, Blumwald's colleague and former teacher, Shimon Gepstein from Technion, the Israel Institute of Technology, had a promoter from a bean plant that fit the bill. Blumwald recalls their chat: "I said, 'I need a promoter that can do this, this, this, and that,' and he said, 'Hey, I have it.' So I invited him to come to my lab, and we started working." Gepstein became a coauthor of the study, and researchers from Japan and Arizona chipped in too.

Rosa Rivero, who hails from Spain, fits right into this international lab. She genetically engineered the tall tobacco in the greenhouse. To describe the science, she likes to draw pictures.

Her black marker squeaks on the whiteboard as she makes a circle. She says it's a plasmid, a little ring of DNA found in bacteria. Bacteria can pass them off to one another; some bacteria can pass them to plants. Rivero makes two little tick marks on her circle, showing that she's added a snippet of new DNA. This is the bean promoter, plus the cytokinin gene from a bacterium. She draws an oval around the circle. The bacterium has taken the plasmid into its body, and it's ready to deliver it to the tobacco. She sketches a beaker full of liquid, which she says is teeming with those bacteria. Finally, she draws a stem with flowers on the end, dipped into the liquid. The bacteria go to work; they "transform" the plant.

Slideshow: Author Hayley Rutger examines how the UC Davis team makes drought-tolerant plants. (Click image to launch show.)

After Rivero adds genes to tobacco, she takes a bit of leaf tissue and turns it into a whole new plant, using hormones and time. This technique, called "tissue culture," has been around since the 1950s and is used to clone plants. Rivero waits for her plants to mature, and then she breeds them for three generations to make sure they carry only the drought-tolerance gene. With tobacco, a generation takes a few months. With plants like rice and cotton, it can take two years. Blumwald was right—there's no quick "poof" here.

But it was worth the time. When Blumwald and Rivero stopped watering the plants for fifteen days, the plain tobacco never recovered. The chimeras sprang back up after drooping slightly. When the scientists grew the plants on 30 percent of the water they usually got, the regular tobacco produced 60 percent fewer seeds than the engineered tobacco. They did this test outdoors in the summer, and they plan to do it for several summers to come, soon with different plants. For now, the tobacco is snug indoors and out of the chill winter wind.

In a room behind plastic curtains, Rivero raises young tobacco in an incubator that works like a mini-greenhouse and looks like a refrigerator. The curtains block most of the noise from the incubation machinery. But its muted whirr permeates the lab, overlain by lively Spanish music from a radio. Rivero dons purple latex gloves and square-rimmed glasses, ties back her curly brown hair, and sets out to understand how more cytokinin makes super tobacco. While other scientists in Blumwald's lab are starting to engineer rice, tomatoes, and cotton, she's studying tobacco in detail.

Rivero calls tobacco "a great model for horticultural plants." It grows fast, making hundreds of tiny seeds that look like coffee grounds and sporting large leaves. "I love them," she says. "When you're working with molecular biology, you need to get RNA and DNA and proteins, and for that you need a lot of plant material." RNA is the molecule that translates DNA's genetic code into proteins. Rivero and her colleagues are studying about 45,000 different bits of RNA in the tobacco to find out which genes might play a role in drought tolerance. So far, the RNA tells them that genes for antioxidants—beneficial chemicals also found in healthy foods like blueberries—work better in the drought-resistant crops, perhaps protecting the leaves from stress.

Photo: Hayley Rutger

This vial, full of chlorophyll from a purified membrane in transgenic tobacco plant cells, may contain a protein that helps the plants resist drought.

Rivero also studies one important protein that a plant must have to make its own food. The protein comes from the green membrane in the leaf that absorbs energy from the sun. Rivero holds up a plastic tube full of emerald liquid. Inside is the pure membrane, containing the green molecule chlorophyll and the protein that might give transgenic plants the advantage. "Maybe this protein is the key. We don't know yet," she says.

Blumwald and Rivero's close look at cytokinin's effect on tobacco is a valuable contribution, says Susheng Gan. The team's work, using cytokinin to counteract stress, "is not the first at all," Gan says, but "this is a good investigation. Nobody knows exactly how cytokinin inhibits senescence [death]."

Gan cautions that if Blumwald's crops overproduce cytokinin during a drought, this could cause a harmful hormonal imbalance. However, Blumwald says, this will not be an issue; his promoter shuts down when cytokinin builds up.

The long way to the fields

Drought will progress as inexorably as Rivero's meticulous experiments. But at the finish line, the western U.S. may have chimerical crops on its side. Blumwald and Rivero plan to fortify three of California's key crops: tomatoes, cotton, and rice. Arcadia Biosciences, Inc. plans to bring their work to fruition, perhaps within eight years.

"We basically build on the research work of somebody like Dr. Blumwald. We spend a lot of time and money validating it in the field," says Arcadia's CEO, Eric Rey. "We often turn around and license the technology to some of the big companies, who then begin the process of putting it into their varieties." Arcadia successfully tested the drought-resistant tobacco in the field in December. Companies are interested but haven't yet bought the license, Rey says.

It usually takes Arcadia seven years to put out a new product. First, their researchers must test everything for safety. They screen the DNA for unexpected changes near the newly inserted genes. They also dig through scientific literature to see whether the transgenic plant might cause allergies, and they feed high doses to laboratory animals. They submit their safety reports to the U.S. Department of Agriculture (USDA), which decides whether the crop might harm the environment once it's unleashed. The USDA can say "no" to any problematic crop. Biotech companies also send safety reports to the Food and Drug Administration (FDA), the government agency that evaluates everything we consume from Advil to apple juice. But no law can force biotech companies to comply with the FDA; it's voluntary. And to some consumers, voluntary safety tests are scary.

A roll of the dice?

In nations of the European Union, a panel of scientists must review transgenic crops, and governments can keep them off store shelves. They're all monitored for environmental effects after hitting the fields, and some are monitored for health effects. Many U.S. consumer advocates want similar laws. DNA chimeras, they say, are unpredictable and poorly controlled. Jeffrey Smith, founder of the nonprofit consumer advocacy group the Institute for Responsible Technology, says he spoke with more than 30 scientists to write *Genetic Roulette*, a book warning consumers that they're rolling the dice at the dinner table.

Three-fourths of consumers, he says, unknowingly eat genetically modified food. The rest knowingly consume it or try to avoid it. No law requires it to be labeled in the U.S., but about 73 percent of our cornfields are engineered to make their own pesticide or to resist herbicide, according to the book. Also, about 93 percent of our soybeans and 87 percent of our upland cotton have patchwork DNA, Smith maintains. Soy and corn creep into all sorts of foods, so Smith tells consumers to be careful.

"In my opinion there is no scientific justification to allow these foods out of the laboratory," he says. "There's economic justification and political justification." He says private funding can bias research, and this puts consumers on thin ice.

At a recent agricultural symposium in Asilomar, California, Smith spoke more about his alarm. He presented a study in which rats ate transgenic potatoes. Scientists later found that the rats' stomach linings looked overgrown, and possibly precancerous. Smith also described a study where rats fed transgenic crops had small offspring that frequently died. "It might be decades before we understand DNA well enough to make these kinds of massive changes in a safe and predictable manner," Smith says. Because the FDA only regulates these foods voluntarily, he believes even problematic ones could end up in our diet.

Arcadia's director of regulatory affairs, Don Emlay, counters that biotech companies would only avoid this voluntary safety check at the risk of incurring "the wrath of the FDA and food companies alike." Any transgenic food that isn't FDA approved will hit a brick wall on the market, he maintains. FDA officials say that to their knowledge, all commercialized transgenic crops today have been through this safety evaluation. "The cost of developing a product is so expensive, you want to know all this before you get too far down the road," Emlay adds.

To address Smith's potato example, Emlay refers to an article by plant biologist Nina Federoff, technology advisor to the U.S. secretary of state. Federoff says the ill effects of the transgenic potatoes most likely came not from adding new DNA but from the cloning process of tissue culture, which is used by both traditional breeders and biotech companies. It can create random changes in DNA. In the potato study, the unaltered potatoes didn't go through tissue culture with the transgenic ones. A biotech firm would typically catch safety problems from tissue culture by feeding its products to laboratory animals.

The California Farm Bureau Federation (CFBF), a nonprofit group of about 91,000 farmers and ranchers, supports research on transgenic crops. "We're in favor of exploring the technology to see what it may offer both for farmers and consumers," says Dave Kranz, CFBF manager of media services. Farmers sometimes express concerns about transgenic crops pollinating other plants in the field, Kranz notes, but they've dealt with pollen problems since before genetic engineering came along.

However, the California Rice Commission takes a more cautious stance. Its official statement declares: "The California Rice Commission believes there should be no field testing of GM [genetically modified] rice." Commission officials declined to say why.

Adapting agriculture

Biotech crops may be too useful to ignore as climate change progresses, Arcadia CEO Rey believes. "I think a decade or so down the road, we're going to see salt tolerance, drought tolerance, heat tolerance, improved cold tolerance, and agriculture that is more robust and more productive." Blumwald agrees, adding that transgenic crops may feed burgeoning populations in the future. "People are going to the cities, people are leaving the land, but our population continues increasing, so we need food," he says.

Researchers have a lot more experiments to do before the descendants of a greenhouse full of chimeras fill western fields. Only time will tell whether these unnatural plants can save us from an unnatural disaster.