AGRICULTURE

SALTWATER SOLUTION

Farmland is being ruined by salty water. Rice and fruits, genetically modified to survive salt, could feed millions

By Mark Harris

ERIC REY PULLS A PLASTIC CONTAINER HALF FULL OF COOKED RICE OUT OF HIS BRIEFCASE. THE FAT, brown grains look like normal rice. They smell like normal rice. When I gingerly raise a few grains to my lips, they even taste like normal rice: soft, chewy and a little bland. I have to stop myself from reaching for a bottle of soy sauce here in the kitchen of Arcadia Biosciences' offices in Seattle—Rey is the chief executive of the biotechnology company—to add a little salt.

My desire for extra flavor is a bit odd because this rice was grown in a salty brine that would kill most plants on the earth. The rice plants were genetically engineered to survive the chemical, mimicking unusual plants called halophytes that flourish on ocean bays, inlets and marshy shorelines. I'm surprised the grains in my mouth don't make my tongue curl. I try a blind taste test comparing them with unmodified rice grown in freshwater, and I can't tell the difference.

"Rice is the most valuable crop in the world," measured by the amount produced in 2012, Rey says, "but we've tested in parts of China where the salinity has gone up and up, and they basically can't grow crops anymore." Rey believes that new understanding of the genes that help halophytes cope with huge doses of salt, combined with modern biotech methods of inserting those genes into rice and other plants, could hold the key to feeding our planet's growing population.

Nearly a quarter of the world's irrigated areas suffer from salty soil caused by poor irrigation practices. Sea-level rises also threaten tens of millions of hectares more farmland with saltwater intrusion. If healthy crops could be grown in such salty regions, they might provide food for tens of millions of people, a vital step toward supporting the extra two billion mouths expected on the earth by midcentury.

This is no pipe dream, says Eduardo Blumwald, a plant biologist at the University of California, Davis, whose work forms the basis of Arcadia's rice. "I believe it's now feasible to grow crops in low-quality, brackish and recycled water, even diluted seawater," he says. About 700 miles south of Seattle, Blumwald's Davis greenhouses are packed with tall, emerald-green rice plants thrusting up from shallow pools of salty water. He and a few other scientists around the world are transferring genes from naturally salt-tolerant halophytes into everyday crops—not just rice but also wheat, barley, cotton and tomatoes.

For these seeds of salvation to take root, however, they will have to move out of greenhouses and prove they can thrive amid real-world storms, droughts and predatory insects. They will also need to survive a tempest of safety and regulatory questions from politicians, scientists and farmers.

Even if the plants themselves are delicious, genetic engineering can leave a nasty taste in people's mouths. They worry the genes may be transferred to other organisms, with unforeseen effects. Such projects, critics say, expose some of poorest and most vulnerable people in the world to these uncertainties. Furthermore, points out Janet Cotter, and environmental consultant, creating food that can be grown in salty conditions simply encourages more poor irrigation practices. "If you've got bad irrigation, then you're on an unsustainable treadmill," she says.

A SALTY TALE

HALOPHYTES, whose very name means "salt plants," can survive in water ranging in salinity from a stiff Bloody Mary to full-on seawater. Mangroves are halophytes. The type of plants is relatively rare and tends to look (and taste) unappetizing, with knobby protuberances, few or ugly leaves, or prominent roots.

Early attempts to popularize halophytes tried to stimulate a market by touting mangroves as a building material, oil-rich succulent halophytes for biofuels, or salt-tolerant bushes for animal forage. In 1998 researchers wrote an article in *Scientific American* envisioning large-scale halophyte farms around the world to feed people. But in the absence of any developed markets for the niche crops they offered, such farms were doomed to failure.

By the time Blumwald began work on halophytes in the mid-1990s, they had been largely dismissed as botanical curiosities. "Most agricultural scientists never thought about salinity," he says. "They were thinking about making food bigger, rounder, more colorful, sweeter."

Blumwald, however, became interested in a protein found in these plants that is called an antiporter. It accelerates the exchange of sodium (salt) and hydrogen ions across a plant's cell membranes. When sodium in water is absorbed by the plant, it disrupts enzymes, the transport of water around the plant and, ultimately, photosynthesis itself. Blumwald found that by genetically engineering everyday species to produce large amounts of this antiporter he was able to breed plants that could grow in water a third as salty as seawater, with few ill effects. The antiporter pushed sodium ions into vacuoles, sealed-off spaces within cells, where they could do no harm. In some natural halophytes, these vacuoles become so big they are called salt bladders. Quinoa, one halophyte that has found its way to tables, has bladders that look like tiny translucent spheres on its leaves.

When Blumwald boosted antiporter levels in some English heirloom tomatoes, the plants grew in water that was "four times as salty as chicken soup," he says. And they produced red, round, sweet, juicy fruit, each weighing several ounces. But while Blumwald's creations thrived in the laboratory, they struggled in the real world. "Everything works in the greenhouse, where you have a relative humidity of 40 percent or more," Blumwald says. As humidity decreases, however, plants lose more moisture from their leaves and defensively close pores. So growing plants is much harder, he notes, "when you go to the field, with a humidity of 5 percent and much less water."

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The problem is that an ability to shed salt is not the only requirement for growing well in salty soil. Plants possess thousands of genes, involved in many biological processes, that can help the organism cope with many kinds of stress, such as heat, drought or salinity. To grow in salty conditions, a plant needs to have multiple genes that change their expression in protective ways when growing conditions become challenging. There is no single magic bullet, says Simon Barak, a senior lecturer in plant sciences at Ben-Gurion University of the Negev in Israel, "But we have developed a computational method to sift through those genes and see which are most likely to be involved in stress tolerance."

Barak constructed a stress gene database, gathering data from published experiments on the plant *Arabidopsis thaliana* (commonly used by agricultural researchers to study botanical processes). Using statistical analyses that allowed him to rank the importance of each gene for plant survival under conditions such as high heat, he identified a number of promising candidate genes.

Then Barak's group ran lab tests on plants with mutated versions of those genes to see how the vegetation coped with harsh conditions. Mutants that showed tolerance to drought, salt or heat were then targeted for further study. "In classical genetic screens for new mutants, you'll screen thousands of plants of which maybe 1 to 3 percent might look interesting," Barak says. "We got a hit rate of 62 percent. We have enough mutants to last us our whole scientific lifetimes."

Other researchers have also homed in on salt survival by blending biology with statistics and computer science. A few years ago, for example, while working at the Central Salt & Marine Chemicals Research Institute in Gujarat, India, geneticist Narendra Singh Yadav found a number of genes associated with salt tolerance in another halophyte, salicornia . He did not know exactly what the genes did, only that his analysis suggested they played an important role. To test his theory, Yadav inserted two of these genes into tobacco, a plant usually quite vulnerable to salt. When grown in water about a third as salty as seawater, the transgenic plants germinated better, had longer roots and shoots, and were larger and leafier than unmodified plants. Although they did not develop visible salt bladders, the plants had lower levels of harmful molecules called reactive oxygen species that accumulate under salt stress. Yadav is now based in Israel with Barak, and his former research group is working on a salt-tolerant version of cotton in Gujarat. "And I think there are still a lot more genes to discover," he says.

IN BRIEF

Nearly a quarter of the world's farmland suffers from increasingly salty soil, which is killing plants.

Geneticists have figured out ways to modify rice and tomatoes with genes that increase salt tolerance.

Such plants could feed millions and save farms, but critics worry about unplanned effects of gene modifications.

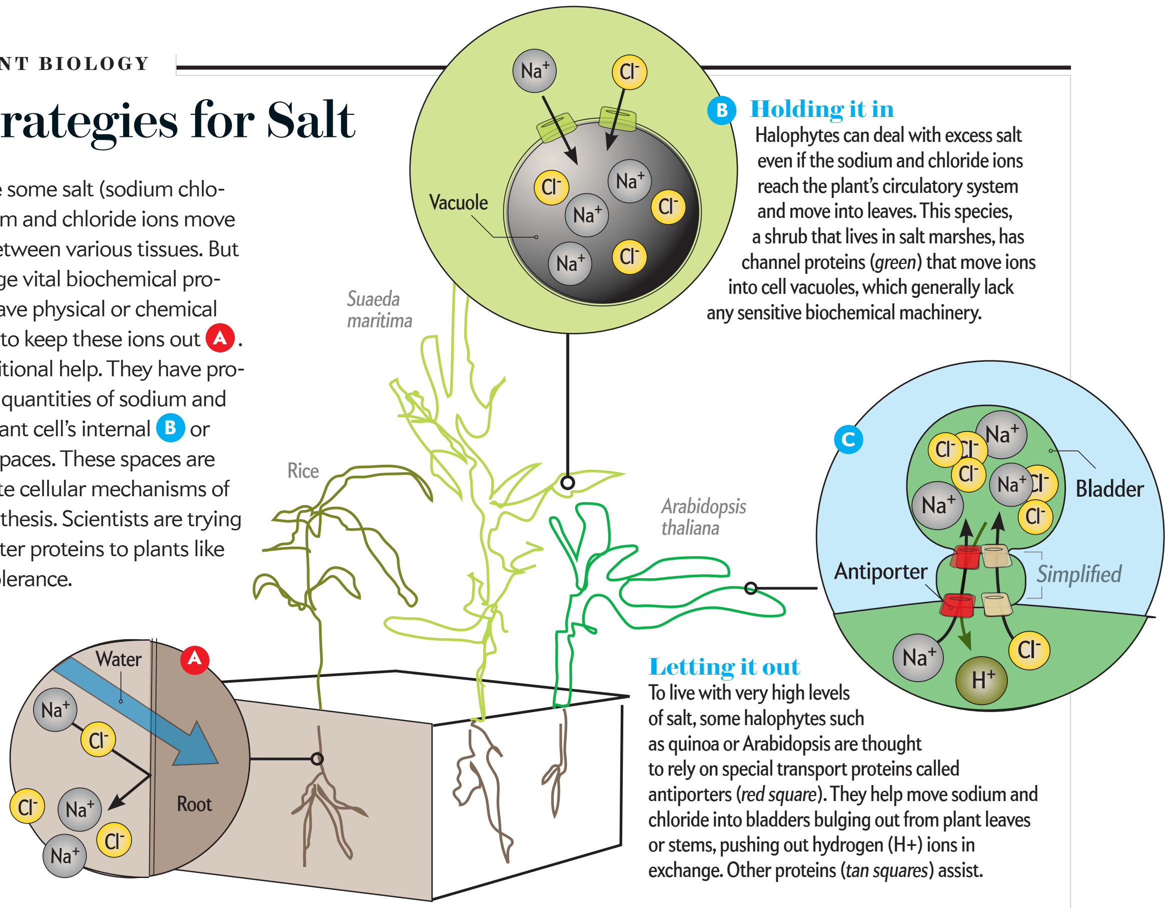
SCIENTIFIC AMERICAN ONLINE Watch a talk about genetically engineering more salt-tolerant crops at ScientificAmerican/jun2016/salt-crops

CONCEPT SKETCH (tight sketch due April 1)

PLANT BIOLOGY

Three Strategies for Salt

All plants can tolerate some salt (sodium chloride) in the soil. Sodium and chloride ions move into plant cells and between various tissues. But high levels can damage vital biochemical processes. Most plants have physical or chemical barriers at their roots to keep these ions out Ⓐ. Halophytes have additional help. They have proteins that move large quantities of sodium and chloride ions into a plant cell's internal Ⓑ or external Ⓒ storage spaces. These spaces are sealed off from delicate cellular mechanisms of growth and photosynthesis. Scientists are trying to add these transporter proteins to plants like rice to improve salt tolerance.



Barrier method
The vast majority of plants are salt-sensitive glycophytes. They have physical and biochemical barriers in their roots that keep out low levels of external sodium (Na+) and chloride (Cl-) ions, while letting water in.

Holding it in
Halophytes can deal with excess salt even if the sodium and chloride ions reach the plant's circulatory system and move into leaves. This species, a shrub that lives in salt marshes, has channel proteins (*green*) that move ions into cell vacuoles, which generally lack any sensitive biochemical machinery.

Letting it out
To live with very high levels of salt, some halophytes such as quinoa or Arabidopsis are thought to rely on special transport proteins called antiporters (*red square*). They help move sodium and chloride into bladders bulging out from plant leaves or stems, pushing out hydrogen (H+) ions in exchange. Other proteins (*tan squares*) assist.

The important thing, Blumwald says, is "to be intelligent without being stupidly optimistic." His group at U.C. Davis has a dozen greenhouses running experiments on thousands of different transgenic plants, from alfalfa and pearl millet to peanuts and rice. Most are modifications of successful commercial crops, and each experiment tries to replicate natural, stressful conditions. Massive fans simulate erratic winds, water is delivered at irregular intervals or in pulses like storms, and salt and heat are applied. "I'm tired of taking our plants to fields and watching them die," he says. "Is it feasible to get crops to grow in seawater? I don't think so. They might grow, but their nutritional value will be really small. But in diluted seawater or recycled water? Surely."

NATURAL FEARS

GENETIC ENGINEERING, however, remains controversial in many parts of the world. Cotter says: "We're never quite sure what else may be affected in the plant and whether that has any implications for food or environmental safety." Cotter prefers a breeding system called marker-assisted selection that uses genomic tools to identify genes for salt tolerance in wild versions of crop plants, then naturally breeds those plants with domesticated plants to reintroduce the gene into plants grown on farms.

Timothy Russell, an agronomist in charge of rice projects for the International Rice Research Institute in Bangladesh, is also skeptical. "There's not a huge problem with GM in my mind, but it's a lot easier to get a conventionally bred variety into the market," he says. "We think we can get reasonably good tolerance to salinity using conventional techniques. Why go down a more complicated way when it's not really necessary?"

One good reason to use GM, advocates say, is that it is faster. Breeding, selecting and rebreeding take time. Genetically engineered salt-tolerant crops will likely beat conventionally bred plants to market, probably within the next four years. The salt-tolerant rice I tasted from Arcadia Biosciences is already halfway through its final field trials in India and is headed for regulatory approval there. The plant produces 40 percent more grain than today's rice in water a tenth as salty as the sea, and Rey expects a subsequent strain to be twice as tolerant again. "Better yields for farmers mean that they make money, we make money and we reduce the load on freshwater resources," he says.

It's a small start, Blumwald feels. "It's a step in the right direction," he says. "Feeding billions more people in the future will require not one success like this but dozens or hundreds." SA

MORE TO EXPLORE

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FROM OUR ARCHIVES

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Illustration by Cherie Sinnen