A DIRE FUNGAL INVADER IS ATTACKING PRACTICALLY THE ONLY BANANA THE WORLD EATS.

PHOTOGRAPHS BY MCNAIR EVANS

CONFRONTING THE BANANAPOCALYPSE

BY ANDREW ZALESKI

THE BEST HOPE FOR THE CAVENDISH MIGHT BE GENETIC MODIFICATION

CAVENDISH BANANAS IN COLOMBIA

TAYLOR FRAZIER-DOUGLAS, LEAD SCIENTIST AT ELO LIFE SYSTEMS' BANANA PROGRAM IN DURHAM, NORTH CAROLINA

DR. BANANA'S FIRST LOVE WAS COFFEE. FOR EIGHT years, Fernando García-Bastidas bred beans in his native Colombia, trying to make a stronger, more flavorful brew. But gradually his passion grew for the banana, the fruit he'd seen daily growing up in Nariño, the region bordering Ecuador to the south and the Pacific to the west. He began doctoral studies at Wageningen University & Research in the Netherlands, studying wild types and supermarket varieties, rare cultivars and crossbreeds—and how Mother Nature sometimes conspires to kill them. Over the years he amassed an Instagram following under the handle @drbananagarcia.

In July 2019, García-Bastidas received an SOS over WhatsApp from a plantation farmer in La Guajira, in northeast Colombia, one of the country's main banana-growing regions. Healthy banana leaves are deeply verdurous; the ones in the pictures were more yellow than green, and their edges were marred by the charcoal color of singed paper. "The only thing I was thinking," he remembers, "is 'I hope not, I hope not, I hope not.'"

A week later he flew from the Netherlands to Colombia and headed for the plantation. Donning a protective suit and boots befitting a surgeon, he trudged into the field. With each whoosh of his pant legs, the mantra reverberated in his mind: "I hope not, I hope not, I hope not."

Soon, García-Bastidas saw drooped and flaxen plants. Carefully, he peeled back layers of one plant's pseudostem—what laypeople might consider the trunk—until he saw black lines running vertically through the vasculature that shuttles water to growing bananas. "When I saw it," he recalls, "I said, 'Ah, shit. This is Fusarium.'"

The possibility was so alarming that for the two weeks García-Bastidas spent in Colombia, he was assigned a handler and placed on lockdown in his hotel. "I couldn't talk to anybody, not even my family," he says. A test he conducted at a lab in Bogotá appeared to confirm his assessment. A month later, after double-checking samples sent back to the Netherlands with him by the Colombian government, García-Bastidas knew for sure: The Grim Reaper of bananas had arrived.

FOR 40 YEARS, FARMERS, SCIENTISTS AND MAJOR producers in the industry have watched with growing anxiety as the fungus García-Bastidas saw, *Fusarium odoratissimum*, or Tropical Race 4, marched through banana plantations in Southeast Asia. In 2013, García-Bastidas reported finding it for the first time outside that region, in Jordan. Soon it spilled into the banana fields of Africa.

Fusarium is naturally occurring and typically spreads when contaminated soil hitches a ride on clothing, shoes or vehicles. In a banana field it burrows into the soil and attacks through the roots, quickly invading a plant's vascular system and choking off the flow of water and nutrients, rotting it from the inside long before bananas appear. Slice open the corm—the bulblike appendage under the soil from which the pseudostem grows—and the infected plant material resembles the brittle embers left after a campfire. And there are no treatments for this. No preventatives, no cures. Even after chewing through every plant, TR4 remains in the soil, ruining the fields for future production.

The fear, always, was that TR4 would creep its way into Latin America, where frost-free weather and rich, alluvial soil has provided the premier place for growing *Musa cavendishii*, the Cavendish, the world's most consumed banana. Although about 1,000 varieties of banana exist, including many that live harmoniously with Fusarium, most are unfit for international trade. They're too small or too seed-filled. Too fragile. Too acidic. More tart and tough than sweet and soft.

By contrast, the Cavendish plant produces a wondrous banana. About a year after it's planted, a secondary stalk emerges from the pseudostem, and the inflorescence, the flowering part that transforms into fruit, appears. Out of that second stalk grows a single bunch of bananas, which can weigh well over 80 pounds. Each bunch contains "hands"—what you buy in the grocery store—that are made up of "fingers," the individual bananas. They're hardy enough to withstand long journeys without bruising. They don't ripen too quickly. They contain no seeds, by virtue of their triploid genomic structure (11 different chromosomes with three copies of each). And yields are consistently high.

As a result, Cavendish bananas make up 99% of global banana exports. In 2022 the Central and South American countries where the market is concentrated shipped more than 16 million tons overseas. Almost every supermarket banana, regardless of the stickered imprimatur of its brand, is a Latin American Cavendish. Americans buy more of them than any other fruit. Without them, the $25 billion global banana industry crumbles.

Really, there's only one problem with the Cavendish: It's highly susceptible to Tropical Race 4. And that made García-Bastidas' identification of TR4 in the world's Cavendish corridor a potentially dire matter. Almost 8,000 acres across 17 banana farms are now under quarantine in Colombia, officially the world's fourth-most-prolific banana exporter. That's only about 6% of the total area where bananas are grown for export in the country, but the fungus is expected to continue to spread. It's already in other South American countries, found in Peru in 2021 and in Venezuela this May. Ecuador, Costa Rica and Guatemala—Nos. 1, 2 and 3, respectively, in terms of banana exports—are on high alert.

After the Colombia discovery, government officials and the country's association of banana growers stepped up efforts at "phytosanitation," hoping to prevent the fungus from escaping infected farms. And Dole Plc and Chiquita Brands International Inc., the largest companies in the banana business, joined a partnership called the Global Alliance Against TR4, which was formed in 2021 to monitor and check the fungus' march through Latin America.

One avenue both companies are exploring is how to increase the Cavendish's resilience. But breeding resistance into the variety is a dubious proposition: Because it's seedless, it's sterile, reproducing only via "sucker," a stalk that grows from the corm to replace the adult plant. Eliminating the fungus is also near impossible. Fumigating the soil has been tried in other infected countries, only to see TR4 repopulate areas thought to be uncontaminated. These challenges have helped push the research toward genetic fortification.

In April, Dole planted dozens of genetically engineered Cavendish plants in one of its infected banana fields in Colombia. The plants were supplied by Elo Life Systems, a startup in Durham, North Carolina. Some of the plants are genetically edited so the genes required to produce fungus-fighting proteins are activated to mount a defense. Others have had proteins from TR4-resistant varieties of banana inserted into their genome, producing a transgenic fruit.

"Banana companies see this fungus as an existential threat," says Elo's chief executive officer, Todd Rands. "We can't afford to fail."

THE CAVENDISH IS ITSELF, IN A SENSE, A CHILD OF Fusarium. It first came to the Western world's attention around 1826, when British naturalist Charles Telfair obtained several of the bananas from China. But its dominant position didn't begin until well after the modern trade in bananas was established. As Dan Koeppel writes in his 2007 book, *Banana: The Fate of the Fruit That Changed the World*, that trade began in 1870, after an American sea captain returned from Jamaica with 160 bunches of a cultivar known as the Gros Michel. It was so novel that, at the Philadelphia Centennial Exhibition six years later, the two attractions that garnered the most attention were the "Big Mike" and Alexander Graham Bell's telephone.

By 1900, Americans were eating 15 million bunches of Gros Michel bananas annually. Three years after that, Fusarium—specifically Race 1—was discovered in a Panamanian Gros Michel field. Slowly but surely, it wiped out millions of acres of bananas, along with millions of dollars.

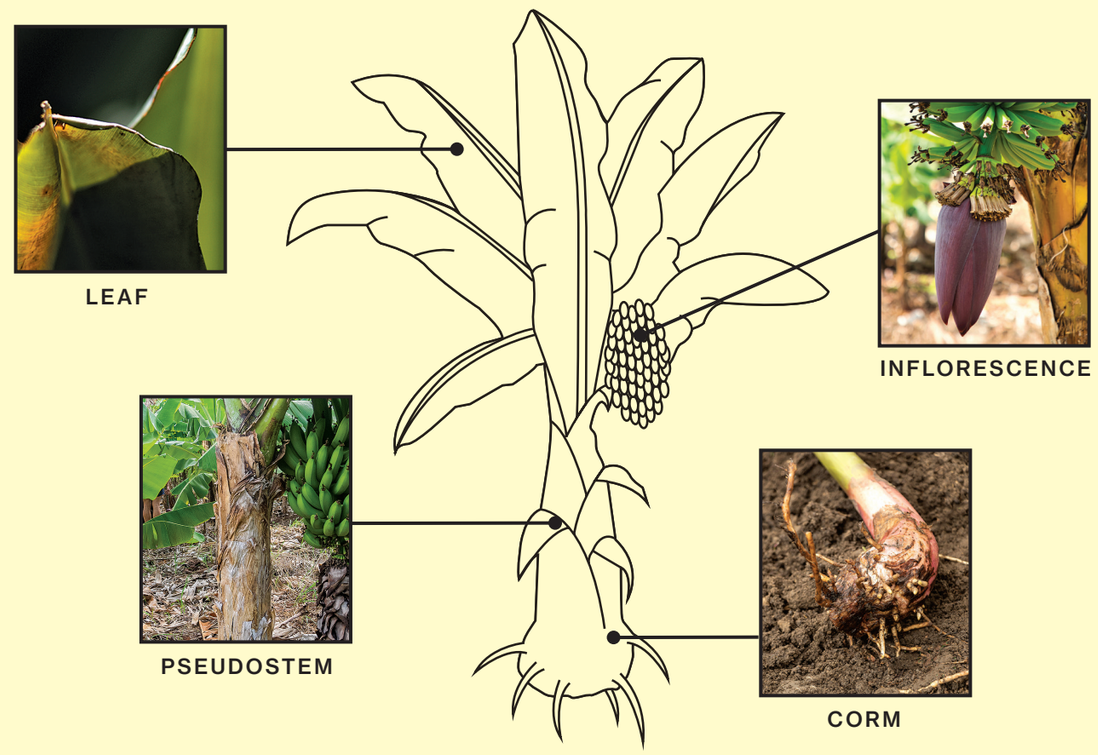
By the mid-1960s, United Fruit (now Chiquita) and Standard Fruit (now Dole)—which had rapaciously built dominant positions in Latin America across the decades, deploying sometimes brutal tactics toward workers and governments alike—had switched from the Gros Michel to the Race 1-resistant Cavendish. In 1965 the last Gros Michel bananas were sold in the US. The Cavendish wasn't as sweet or as firm as the Gros Michel, but it was the best option available for widespread export.

It may seem short-sighted for the world to rely on a single banana, but monocultural mass-production ensures high yields and controllable costs by standardizing growing and harvesting methods. That's how bananas, shipped to far-flung locations, became a $25 billion industry. "We call it the giant with the feet of clay," García-Bastidas says. "It's such big business, and it relies on one simple variety." It wasn't until the 1980s, when the Cavendish was planted in Southeast Asia, that its vulnerability to Tropical Race 4 was identified.

The vast banana estates of Malaysia and Indonesia were particularly at risk. Yet the response there was muted, even ▶

PREVIOUS SPREAD: BANANAS: LAURENT VAUTRIN/DOLE. THIS SPREAD: ILLUSTRATION BY 731. LEAF: PHOTOGRAPH BY MCNAIR EVANS FOR BLOOMBERG BUSINESSWEEK. INFLORESCENCE: ALAMY. PSEUDO STEM: JACEK SOPOTNICKI/ALAMY. ROOT: GHEORGHE MINDU/ALAMY.

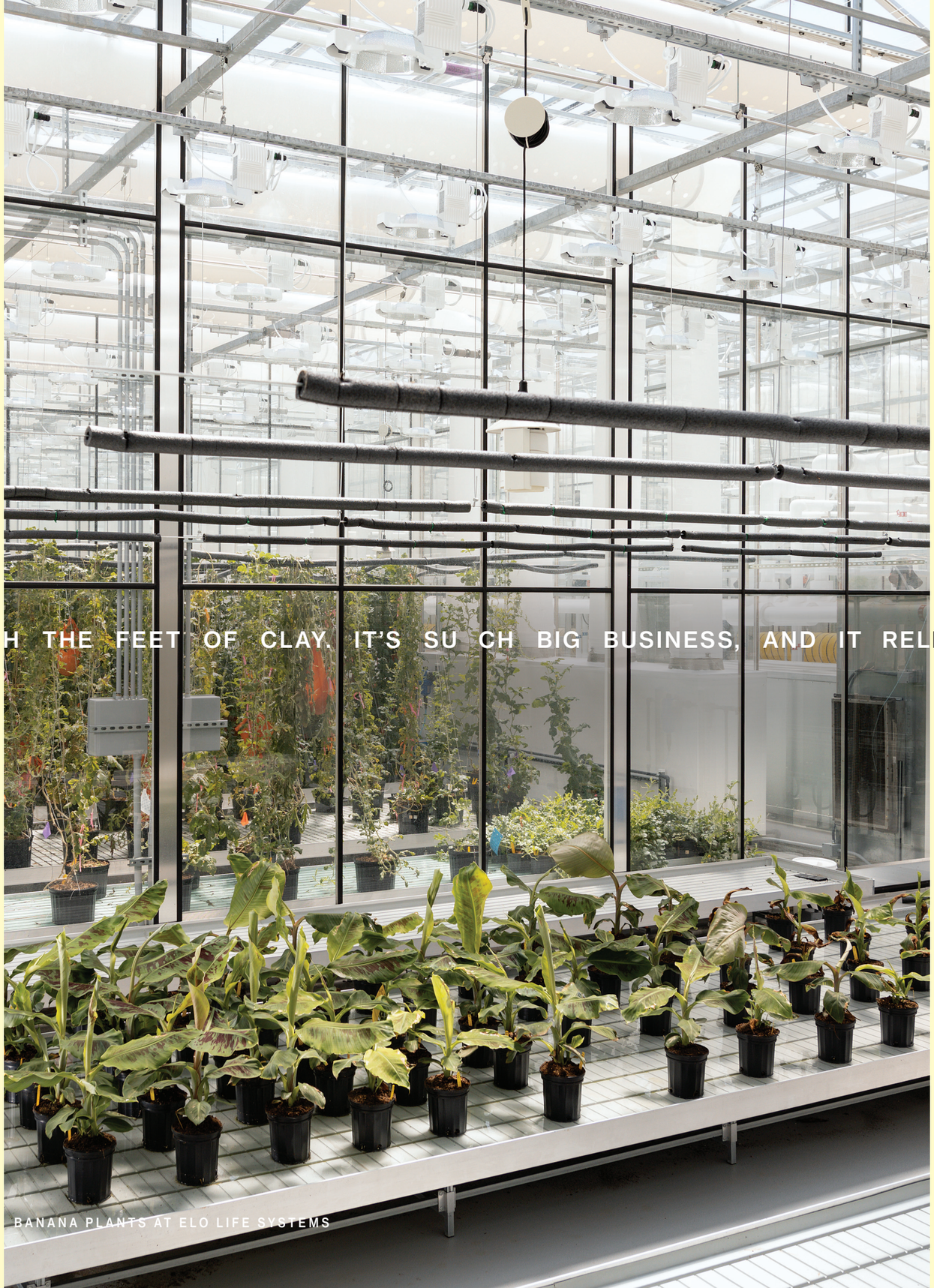
ANATOMY OF A CAVENDISH PLANT



◀ cavalier. Koeppel recounts that one article in Malaysia's *New Straits Times* "portrayed the issue more as a challenge than a calamity, something the country's respected scientific community could easily brush aside." Meanwhile, banana plants were dying. One 5,000-acre Fresh Del Monte plantation in Sumatra was hit especially hard. "The reality," Koeppel writes of the Southeast Asia TR4 outbreak, "was a total—and precipitous—wipeout."

Tropical Race 4 is following the same trajectory as the earlier Race 1, having leapt across the Pacific to infect Latin America's banana fields. But researchers contend that the fungus was lurking in the soils of Asian banana-growing regions all along and merely escaped. And this, García-Bastidas says, is the truly scary thing. Various strains of Fusarium are distinct forms, not evolutionary iterations, that have likely existed for millenniums. There's even a strain known just as Race 4, which infects stressed or weakened Cavendish plants growing in colder, subtropical environments. All that needed to happen to unleash TR4—especially pernicious because it infects Cavendish in all climatic conditions—was for the industry to plant rows and rows of the same susceptible banana.

By 2016, Dole was already engaged with the Honduran Foundation for Agricultural Research, trying to identify banana varieties resistant to the fungus. Five years after that, the company was citing TR4 as a serious threat in a filing to the US government, titling one section "Tropical Race 4 may impose significant costs and losses on our business." The next year, Dole wrote, "We may be unable to prevent TR4's spread or develop bananas fully resistant to the disease." The company declined to comment substantively for this story but said through a spokesman that "although the TR4 risk is a concern, Dole is strongly engaged in combating it." So far, it's spent almost $20 million on quarantine and prevention efforts. It's also been looking for another way—and that's why it began collaborating with Elo Life Systems.



BANANA PLANTS AT ELO LIFE SYSTEMS

"WE CALL IT THE GIANT WITH THE FEET OF CLAY. IT'S SU CH BIG BUSINESS, AND IT RELIES ON ONE SIMPLE VARIETY"

IN JULY I TRAVELED TO DURHAM, WHERE ELO IS working on its Cavendish genetic-modification project. The company's headquarters is situated in a suburban business park, an inconspicuous site with an auspicious history. Elo's labs are located in the same building where Mary-Dell Chilton—who, in the early 1980s, created the first genetically modified crop by inserting a yeast gene into a tobacco plant—spent decades heading biotechnology research for Syngenta AG. Under Chilton's leadership, Syngenta was the first to commercialize *Bt* corn, which was genetically modified to express a protein that kills the larvae of European and southwestern corn borers. For farmers, it meant no longer having to hose down fields with gallons of insecticide, though as with all genetically modified foods, it wasn't without its critics or controversies. To cite one example, in 1998 scientists at Cornell University found that *Bt* corn produced pollen capable of killing the caterpillars that become monarch butterflies, considered an endangered species by the International Union for Conservation of Nature.

Rands, Elo Life Systems' CEO since 2022, refers to the company's specialty as "molecular farming": growing ingredients—sweeteners, proteins, starches and flavors—by reconstructing the existing natural pathways that make these ingredients in plants. One of its pioneering techniques was to take a genetic pathway that produces a commercially useful sweetener in Chinese monk fruit and reproduce it in the genomes of watermelons, sugar beets and other crops grown in the US.

Matt DiLeo, Elo's vice president for product development with a Ph.D. in plant pathology, told me as we began touring the facility that the company's work on the Cavendish began in 2020. Aware of the threat TR4 posed, it reached out to Dole about forming a partnership. He guided me to a wing that houses the startup's growth chambers—sterile white rooms whose 82F temperature is maintained by long, cylindrical overhead heat lamps. The air inside was sticky, vicariously transporting me to the Latin American fields where bananas are grown. Transparent plastic containers, each one bar-coded, were spread among three shelves along one wall. Sealed inside each was a tiny banana shoot sitting in a chemical medium of nutrients and hormones to nurture minuscule roots.

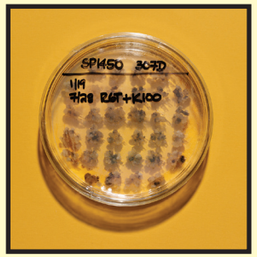
These are the modified plants, and Elo propagates many identical shoots from each one. Some have outside genes inserted into their DNA; others possess a version of their original genome that's been modified to tell the plant to express a specific protein. To test whether the baby plants show signs of resisting TR4, Elo's scientists remove the shoots, dip them into a solution of fungal spores and plant them in soil in a separate growth chamber. "Then it takes 13 days to either kill the plants or not," DiLeo said.

The Cavendish contains more than 30,000 genes, exceeding the 20,000 or so found in a human, but Elo's scientists are studying only about 100 targets. Some are Cavendish genes that might be switched on or off to kick-start a disease response; some are genes from other bananas that might confer resistance. Elo arrived at those targets by identifying differences between the Cavendish genome and the genomes of TR4-resistant bananas and related species, such as plantains. Find a distinction, and you may find the gene that could protect the Cavendish. The work took about three years and a good deal of computational biology.

Fusarium fungal spores are devious, staying dormant until they detect banana roots. Researchers don't know exactly how some banana plants fight off the fungus. According to Elo, it might be the case that resistant cultivars stop spores by rapidly generating gels and gums in the opening stages of infection. ▶

LAB COMPONENTS

Cavendish plant growth at Elo Life Systems



EMBRYO CLUSTERS

EMBRYOS GROWING INTO SHOOTS

PETRI DISH COVERED WITH TR4

SHOOTS IN A GROWTH MEDIUM

CLUSTER OF SHOOTS

SHOOTS READY FOR ROOT GENERATION, THEN PLANTING IN SOIL

◀ These block Fusarium from moving up into the pseudostem, giving the plant enough time to activate fungus-fighting proteins. Susceptible cultivars such as the Cavendish activate their disease responses much more slowly or not at all.

After we finished in the growth chambers, we entered the lab where Jack Wilkinson, Elo's director of discovery, investigates how Cavendish plants can confront infection more quickly. "If you can just slow down the fungus, that gives the plant a chance to protect itself," he said.

The "discovery" in Wilkinson's title here entails identifying the right antifungal material. He previously worked for Calgene Inc., the company that designed the Flavr Savr tomato, the first transgenic, commercially grown food deemed safe for human consumption by the US Food and Drug Administration. Using modified yeast, Wilkinson grows banana genes in small cell-culture plates until they start expressing antifungal proteins. Once he's developed a batch of different proteins, he isolates them from the yeast and dumps them into other plates containing Fusarium spores.

Wilkinson showed me a petri dish filled with antifungal proteins and little black dots–TR4 spores sitting quietly, doing nothing. Their inactivity meant the proteins were successfully inhibiting Fusarium growth. If they weren't working, the spores would have been proliferating in long black strands.

Proteins that stop or slow Fusarium in the petri dish are sent to tissue culture, a lab directly across from Wilkinson's and the next stop on my tour. This is where Taylor Frazier-Douglas, lead scientist of Elo's banana program, creates the actual banana plants. For genetically edited Cavendish, she adds enzyme reagents that change the genome inside cells. For transgenic Cavendish, she uses soil bacteria to insert novel banana genes into the cells. The plants that result look like caramel popcorn in their early stages and take anywhere from 6 to 10 months to germinate. They're transferred to the plastic containers only after tiny leaves emerge.

At the back of the tissue-culture lab are several chambers, each about the size of an industrial refrigerator. They collectively contain about 450 banana plants with various combinations of genetic material, some growing in petri dishes, others growing as tiny shoots inside plastic containers. The hope is that at least one will survive soil saturated with TR4.

"Most people have no idea that the bananas they eat every day are on the verge of extinction," Frazier-Douglas said. "I want my kids to enjoy bananas the way I enjoyed bananas."

OTHERS ARE ATTEMPTING TO ACCOMPLISH THE SAME feat as Elo. James Dale, head of the Banana Biotechnology Program at Queensland University of Technology in Brisbane, Australia, is a leader in *M. cavendishii* metamorphosis. His achievements include making one of the world's first genetically transformed Cavendish bananas in 1994. (Neither you nor anyone else is already eating a genetically modified banana; Dale did this for research purposes only, after TR4 jumped the water and began decimating Australia's Cavendish crop.) "The outbreak in South America has absolutely changed the environment," he says. "People maybe really will need a genetically modified banana if we're going to keep growing the Cavendish."

Dale's new Cavendish, dubbed QCAV-4, contains a gene from a wild Southeast Asian banana. It switches on systemic resistance in the Cavendish, so that, even if Fusarium invades the plant, it doesn't do any damage to the fruit. In field trials, Dale says QCAV-4 has a survival rate greater than 90%. Australian authorities are currently evaluating it and expect to make a ruling about its safety in April 2024. If QCAV-4 gets the OK, it would be, as far as Dale knows, the first genetically modified banana approved for consumption. From there, he says, he'll conduct more field trials in different environments.

If there's one reason banana lovers–consumers, companies and fruit scientists alike–can feel optimistic about the fight, it's the contrast with the lax response to Race 1's charge into the Western Hemisphere. The Gros Michel was eventually ravaged in part because the problem was pushed off instead of met head-on, with growers ignoring the fungus and simply opening up new fields for cultivation. This time everyone is being much more aggressive. "The important thing is that one of us is successful, because this fruit is so important to so many people," DiLeo says.

The potential catch is the use of gene-altering technology. Whether consumers would accept genetically modified bananas is uncertain. Dole concedes in its 2022 disclosure forms that shoppers and governments might view them unfavorably. "It is possible that new restrictions on GMO products will be imposed in major territories for some of our products or that our customers will decide to purchase fewer GMO products or not buy GMO products at all," the company wrote. One paper published in 2018, not even a year before García-Bastidas found TR4 in Colombia, noted that although 88% of scientists think genetically modified foods are safe, only 37% of Americans agree. The US passed federal legislation in 2022 requiring that the terms "bioengineered" or "derived from bioengineering" be printed on the labels of foods with genetically modified ingredients, and the European Union has strict regulations governing genetically modified crops. Both regions import huge numbers of Cavendish bananas.

If people want to keep eating them, though, we may not have a choice. "We've hit the limit," DiLeo says. "The only way that we're going to solve this is if we use biotechnology."

FOR ALL THAT GENETIC MODIFICATION PROMISES, other scientists working on the South American TR4 outbreak see a case for diversification instead. "I know people are used to eating Cavendish, but we need to rethink the overall banana production system," says Miguel Dita, a plant pathologist in Colombia for the Alliance of Bioversity International and the International Center for Tropical Agriculture.

Dita acknowledges that developing a banana with similar qualities to the Cavendish through conventional breeding is "quite difficult." If a new banana were to assume the mantle, it would have to be disease-resistant, high-yielding and palatable to billions of people, with skin thick enough to facilitate transportation and a ripening profile that keeps it from spoiling before reaching its destination. "That's a big ask," Dale says. "There are certainly bananas that have been bred conventionally that do have disease resistance and some of those characteristics, but I've not seen anything close to a Cavendish coming out of any of the breeding programs."

This doesn't mean the approach is hopeless. In the 1980s, Brazilian researchers developed a Fusarium-resistant banana–it just tasted more like "an apple or unripe pear," Koeppel writes in his book. And this year, Chiquita, which didn't respond to a request for comment, announced a partnership with university researchers in Wageningen. Led by García-Bastidas, the project is seeking to produce a TR4-resistant banana that tastes like the Cavendish, as well as new cultivars resistant to a variety of diseases. A first test batch of bananas was recently planted in the Philippines.

Until an alternative can be found, whether genetically modified or not, countries are doing what they can to contain the spread. Colombia's Ministry of Agriculture and Rural Development, working in tandem with the Association of Banana Growers of Colombia, has invested almost $5 million since 2019 on various sanitation and containment projects. They include the construction of washing stations at plantations to clean soil off transport trucks, purchasing about 42,000 liters of disinfectant to clean equipment and installing more than 1,300 miles of wire fencing to enclose stricken banana plants. These are important, if probably insufficient, steps. "What we've learned over and over in the history of plant diseases is that even when you have these huge quarantine efforts, it buys you time, but not a lot," Elo's DiLeo told me.

Toward the end of my tour of the company's Durham offices, he brought me to its 5,000-square-foot research greenhouse, on the other side of the business park. Some of the space is reserved for the watermelons and sugar beets Elo is using to produce monk fruit sweetener. About a fifth is for the new lines of Cavendish bananas. Shoots that survive the initial 13-day test are discarded, but genetic copies of them are eventually potted in the greenhouse. After they've grown for about two months, they're hit with what would normally be a lethal dose of Tropical Race 4–more than they'd encounter in the field.

As DiLeo and I walked through the greenhouse, I saw row after row of Cavendish that had been subjected to the fungus, about 100 plants in all. Some were wilted and black–dead. Interspersed among those, though, were others still in the fight. It was too soon to tell if they'd make it six months, or nine months, or beyond a year–never mind thriving at scale, gaining regulatory approval or reaching consumers. But their pseudostems were still intact. Each plant's blades were a lush, verdant green. Their leaves, far from drooping, drank in the sunlight. And as early as next year, the bananas hanging in bunches could be the mighty Cavendish, unmistakable in all aspects save for one: a newfound resilience against a fungal invader. Ⓑ