BIOTECHNOLOGY

are engineered foods Evil?

Proponents of genetically modified crops say the technology is the only way to feed a warming, increasingly populous world. Critics say we tamper with nature at our peril. Who is right?

By David H. Freedman

ROBERT GOLDBERG SAGS INTO HIS DESK CHAIR AND GESTURES AT THE air. "Frankenstein monsters, things crawling out of the lab," he says. "This the most depressing thing I've ever dealt with."

Goldberg, a plant molecular biologist at the University of California, Los Angeles, is not battling psychosis. He is expressing despair at the relentless need to confront what he sees as bogus fears over the health risks of genetically modified (GM) crops. Particularly frustrating to him, he says, is that this debate should have ended decades ago, when researchers produced a stream of exonerating evidence: "Today we're facing the same objections we faced 40 years ago."

Across campus, David Williams, a cellular biologist who specializes in vision, has the opposite complaint. "A lot of naive science has been involved in pushing this technology," he says. "Thirty years ago we didn't know that when you throw any gene into a different genome, the genome reacts to it. But now anyone in this field knows the genome is not a static environment. Inserted genes can be transformed by several different means, and it can happen generations later." The result, he insists, could very well be potentially toxic plants slipping through testing.

Williams concedes that he is among a tiny minority of biologists raising sharp questions about the safety of GM crops. But he says this is only because

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the field of plant molecular biology is protecting its interests. Funding, much of it from the companies that sell GM seeds, heavily favors researchers who are exploring ways to further the use of genetic modification in agriculture. He says that biologists who point out health or other risks associated with GM crops—who merely report or defend experimental findings that imply there may be risks—find themselves the focus of vicious attacks on their credibility, which leads scientists who see problems with GM foods to keep quiet.

Whether Williams is right or wrong, one thing is undeniable: despite overwhelming evidence that GM crops are safe to eat, the debate over their use continues to rage, and in some parts of the world, it is growing ever louder. Skeptics would argue that this contentiousness is a good thing—that we cannot be too cautious when tinkering with the genetic basis of the world's food supply. To researchers such as Goldberg, however, the persistence of fears about GM foods is nothing short of exasperating. "In spite of hundreds of millions of genetic experiments involving every type of organism on earth," he says, "and people eating billions of meals without a problem, we've gone back to being ignorant."

So who is right: advocates of GM or critics? When we look carefully at the evidence for both sides and weigh the risks and benefits, we find a surprisingly clear path out of this dilemma.

BENEFITS AND WORRIES

THE BULK OF THE SCIENCE on GM safety points in one direction. Take it from David Zilberman, a U.C. Berkeley agricultural and environmental economist and one of the few researchers considered credible by both agricultural chemical companies and their critics. He argues that the benefits of GM crops greatly outweigh the health risks, which so far remain theoretical. The use of GM crops "has lowered the price of food," Zilberman says. "It has increased farmer safety by allowing them to use less pesticide. It has raised the output of corn, cotton and soy by 20 to 30 percent, allowing some people to survive who would not have without it. If it were more widely adopted around the world, the price [of food] would go lower, and fewer people would die of hunger."

In the future, Zilberman says, those advantages will become all the more significant. The United Nations Food and Agriculture Organization estimates that the world will have to grow 70 percent more food by 2050 just to keep up with population growth. Climate change will make much of the world's arable land more difficult to farm. GM crops, Zilberman says, could produce higher yields, grow in dry and salty land, withstand high and low temperatures, and tolerate insects, disease and herbicides.

Despite such promise, much of the world has been busy banning, restricting and otherwise shunning GM foods. Nearly all the corn and soybeans grown in the U.S. are genetically modified, but only two GM crops, Monsanto's MON810 maize and BASF's Amflora potato, are accepted in the European Union. Eight E.U. nations have banned GM crops outright. Throughout Asia, including in India and China, governments have yet to approve most GM crops, including an insect-resistant rice that produces higher yields with less pesticide. In Africa, where millions go hungry, several nations have refused to import GM foods in spite of their lower costs (the result of higher yields and a reduced need for water and pesticides). Kenya has banned them altogether amid widespread malnutrition. No country has definite plans to grow Golden Rice, a crop engineered to deliver more vitamin A than spinach (rice normally has no vitamin A), even though vitamin A deficiency causes more than one million deaths annually and half a million cases of irreversible blindness in the developing world.

Globally, only a tenth of the world's cropland includes GM plants. Four countries—the U.S., Canada, Brazil and Argentina—grow 90 percent of the planet's GM crops. Other Latin American countries are pushing away from the plants. And even in the U.S., voices decrying genetically modified foods are becoming louder. At press time, at least 20 states are considering GM-labeling bills.

The fear fueling all this activity has a long history. The public has been worried about the safety of GM foods since scientists at the University of Washington developed the first genetically modified tobacco plants in the 1970s. In the mid-1990s, when the first GM crops reached the market, Greenpeace, the Sierra Club, Ralph Nader, Prince Charles and a number of celebrity chefs took highly visible stands against them. Consumers in Europe became particularly alarmed: a survey conducted in 1997, for example, found that 69 percent of the Austrian public saw serious risks in GM foods, compared with only 14 percent of Americans.

In Europe, skepticism about GM foods has long been bundled with other concerns, such as a resentment of American agribusiness. Whatever it is based on, however, the European attitude reverberates across the world, influencing policy in countries where GM crops could have tremendous benefits. "In Africa, they don't care what us savages in America are doing," Zilberman says. "They look to Europe and see countries there rejecting GM, so they don't use it." Forces fighting genetic modification in Europe have rallied support for "the precautionary principle," which holds that given the kind of catastrophe that would emerge from loosing a toxic, invasive GM crop on the world, GM efforts should be shut down until the technology is proved absolutely safe.

But as medical researchers know, nothing can really be "proved safe." One can only fail to turn up significant risk after trying hard to find it—as is the case with GM crops.

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IN BRIEF

The vast majority of the research on genetically modified (GM) crops suggests that they are safe to eat and that they have the potential to feed millions of people worldwide who currently go hungry. **Yet not all criticisms** of GM are so easily rejected, and pro-GM scientists are often dismissive and even unscientific in their rejection of the counterevidence. **A careful analysis** of the risks and benefits argues for expanded deployment *and* safety testing of GM crops.

How to Build a Better Plant

Genetic modification and conventional plant breeding have much in common: both are ways of producing new crops by altering plant genomes. The differences have to do with the tools used, the number of genes swapped and the comfort level of the average consumer.

Conventional Crossbreeding

Since the earliest days of agriculture, humans have been selecting plants with desirable characteristics and crossbreeding them to make new, even more desirable specimens—in this case, a tomato plant that combines the blight resistance of one parent with the high fruit yield of another.

Genetic Modification

In the 1970s scientists began developing methods for quickly inserting specific genes from one plant into the DNA of another—a quick, targeted means to the same end as conventional crossbreeding. Early researchers used disarmed *Agrobacterium* to smuggle genes into plant cells. Later, scientists at Cornell University developed the DNA particle gun method, in which engineers shoot DNA-coated tungsten balls through the cell walls of the target plant by firing them out of a blank gunpowder cartridge.

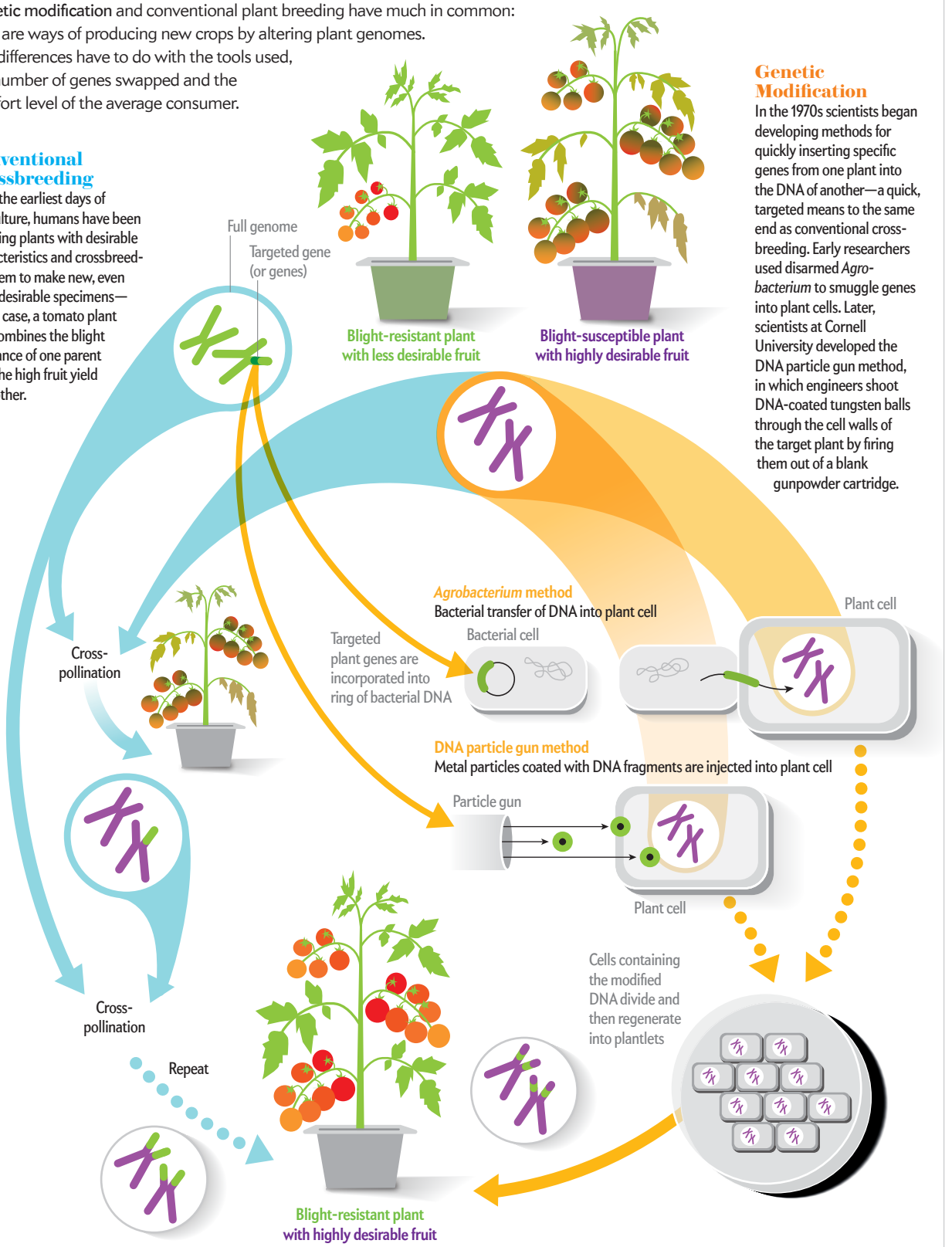

Illustration by Jen Christiansen

A CLEAN RECORD

THE HUMAN RACE has been selectively breeding crops, thus altering plants' genomes, for millennia. Ordinary wheat has long been strictly a human-engineered plant; it could not exist outside of farms, because its seeds do not scatter. For some 60 years scientists have been using "mutagenic" techniques to scramble the DNA of plants with radiation and chemicals, creating strains of wheat, rice, peanuts and pears that have become agricultural mainstays. The practice has inspired little objection from scientists or the public and has caused no known health problems.

The difference is that selective breeding or mutagenic techniques tend to result in large swaths of genes being swapped or altered. GM technology, in contrast, enables scientists to insert into a plant's genome a single gene (or a few of them) from another species of plant or even from a bacterium, virus or animal. Supporters argue that this precision makes the technology much less likely to produce surprises. Most plant molecular biologists also say that in the highly unlikely case that an unexpected health threat emerged from a new GM plant, scientists would quickly identify and eliminate it. "We know where the gene goes and can measure the activity of every single gene around it," Goldberg says. "We can show exactly which changes occur and which don't." [For more on how GM plants are analyzed for health safety, see "The Risks on the Table," by Karen Hopkin; SCIENTIFIC AMERICAN, April 2001.]

And although it might seem creepy to add virus DNA to a plant, doing so is, in fact, no big deal, proponents say. Viruses have been inserting their DNA into the genomes of crops, as well as humans and all other organisms, for millions of years. They often deliver the genes of other species while they are at it, which is why our own genome is loaded with genetic sequences that originated in viruses and nonhuman species. "When GM critics say that genes don't cross the species barrier in nature, that's just simple ignorance," says Alan McHughen, a plant molecular geneticist at U.C. Riverside. Pea aphids contain fungi genes. Triticale is a century-plus-old hybrid of wheat and rye found in some flours and breakfast cereals. Wheat itself, for that matter, is a cross-species hybrid. "Mother Nature does it all the time, and so do conventional plant breeders," McHughen says.

Could eating plants with altered genes allow new DNA to work its way into our own? It is theoretically possible but hugely improbable. Scientists have never found genetic material that could survive a trip through the human gut and make it into cells. Besides, we are routinely exposed to—we even consume—the viruses and bacteria whose genes end up in GM foods. The bacterium *B. thuringiensis,* for example, which produces proteins fatal to insects, is sometimes enlisted as a natural pesticide in organic farming. "We've been eating this stuff for thousands of years," Goldberg says.

In any case, proponents say, people have consumed as many as trillions of meals containing genetically modified ingredients over the past few decades. Not a single verified case of illness has ever been attributed to the genetic alterations. Mark Lynas, a prominent anti-GM activist who last year publicly switched to strongly supporting the technology, has pointed out that every single news-making food disaster on record has been attributed to non-GM crops, such as the *Escherichia coli*–infected organic bean sprouts that killed 53 people in Europe in 2011.

Critics often disparage U.S. research on the safety of genetically modified foods, which is often funded or even conducted by GM companies, such as Monsanto. But much research on the subject comes from the European Commission, the administrative body of the E.U., which cannot be so easily dismissed as an industry tool. The European Commission has funded 130 research projects, carried out by more than 500 independent teams, on the safety of GM crops. None of those studies found any special risks from GM crops.

Plenty of other credible groups have arrived at the same conclusion. Gregory Jaffe, director of biotechnology at the Center for Science in the Public Interest, a science-based consumer-watchdog group in Washington, D.C., takes pains to note that the center has no official stance, pro or con, with regard to genetically modifying food plants. Yet Jaffe insists the scientific record is clear. "Current GM crops are safe to eat and can be grown safely in the environment," he says. The American Association for the Advancement of Science, the American Medical Association and the National Academy of Sciences have all unreservedly backed GM crops. The U.S. Food and Drug Administration, along with its counterparts in several other countries, has repeatedly reviewed large bodies of research and concluded that GM crops pose no unique health threats. Dozens of review studies carried out by academic researchers have backed that view.

Opponents of genetically modified foods point to a handful of studies indicating possible safety problems. But reviewers have dismantled almost all of those reports. For example, a 1998 study by plant biochemist Árpád Pusztai, then at the Rowett Institute in Scotland, found that rats fed a GM potato suffered from stunted growth and immune system–related changes. But the potato was not intended for human consumption—it was, in fact, designed to be toxic for research purposes. The Rowett Institute later deemed the experiment so sloppy that it refuted the findings and charged Pusztai with misconduct.

Similar stories abound. Most recently, a team led by Gilles-Éric Séralini, a researcher at the University of Caen Lower Normandy in France, found that rats eating a common type of GM corn contracted cancer at an alarmingly high rate. But Séralini has long been an anti-GM campaigner, and critics charged that in his study, he relied on a strain of rat that too easily develops tumors, did not use enough rats, did not include proper control groups and failed to report many details of the experiment, including how the analysis was performed. After a review, the European Food Safety Authority dismissed the study's findings. Several other European agencies came to the same conclusion. "If GM corn were that toxic, someone would have noticed by now," McHughen says. "Séralini has been refuted by everyone who has cared to comment."

Some scientists say the objections to GM food stem from politics rather than science—that they are motivated by an objection to large multinational corporations having enormous influence over the food supply; invoking risks from genetic modification just provides a convenient way of whipping up the masses against industrial agriculture. "This has nothing to do with science," Goldberg says. "It's about ideology." Former anti-GM activist Lynas agrees. He recently went as far as labeling the anti-GM crowd "explicitly an antiscience movement."

PERSISTENT DOUBTS

NOT ALL OBJECTIONS to genetically modified foods are so easily dismissed, however. Long-term health effects can be subtle and nearly impossible to link to specific changes in the environment. Scien-

tists have long believed that Alzheimer's disease and many cancers have environmental components, but few would argue we have identified all of them.

And opponents say that it is not true that the GM process is less likely to cause problems simply because fewer, more clearly identified genes are switched. David Schubert, an Alzheimer's researcher who heads the Cellular Neurobiology Laboratory at the Salk Institute for Biological Studies in La Jolla, Calif., asserts that a single, well-characterized gene can still settle in the target plant's genome in many different ways. "It can go in forward, backward, at different locations, in multiple copies, and they all do different things," he says. And as U.C.L.A.'s Williams notes, a genome often continues to change in the successive generations after the insertion, leaving it with a different arrangement than the one intended and initially tested. There is also the phenomenon of "insertional mutagenesis," Williams adds, in which the insertion of a gene ends up quieting the activity of nearby genes.

True, the number of genes affected in a GM plant most likely will be far, far smaller than in conventional breeding techniques. Yet opponents maintain that because the wholesale swapping or alteration of entire packages of genes is a natural process that has been happening in plants for half a billion years, it tends to produce few scary surprises today. Changing a single gene, on the other hand, might turn out to be a more subversive action, with unexpected ripple effects, including the production of new proteins that might be toxins or allergens.

Opponents also point out that the kinds of alterations caused by the insertion of genes from other species might be more impactful, more complex or more subtle than those caused by the intraspecies gene swapping of conventional breeding. And just because there is no evidence to date that genetic material from an altered crop can make it into the genome of people who eat it does not mean such a transfer will never happen—or that it has not already happened and we have yet to spot it. These changes might be difficult to catch; their impact on the production of proteins might not even turn up in testing. "You'd certainly find out if the result is that the plant doesn't grow very well," Williams says. "But will you find the change if it results in the production of proteins with long-term effects on the health of the people eating it?"

It is also true that many pro-GM scientists in the field are unduly harsh—even unscientific—in their treatment of critics. GM proponents sometimes lump every scientist who raises safety questions together with activists and discredited researchers. And even Séralini, the scientist behind the study that found high cancer rates for GM-fed rats, has his defenders. Most of them are nonscientists, or retired researchers from obscure institutions, or nonbiologist scientists, but the Salk Institute's Schubert also insists the study was unfairly dismissed. He says that as someone who runs drug-safety studies, he is well versed on what constitutes a good-quality animal toxicology study and that Séralini's makes the grade. He insists that the breed of rat in the study is commonly used in respected drug studies, typically in numbers no greater than in Séralini's study; that the methodology was standard; and that the details of the data analysis are irrelevant because the results were so striking.

Schubert joins Williams as one of a handful of biologists from respected institutions who are willing to sharply challenge the GM-foods-are-safe majority. Both charge that more scientists would speak up against genetic modification if doing so did not invariably lead to being excoriated in journals and the media. These attacks, they argue, are motivated by the fear that airing doubts could lead to less funding for the field. Says Williams: "Whether it's conscious or not, it's in their interest to promote this field, and they're not objective."

Both scientists say that after publishing comments in respected journals questioning the safety of GM foods, they became the victims of coordinated attacks on their reputations. Schubert even charges that researchers who turn up results that might raise safety questions avoid publishing their findings out of fear of repercussions. "If it doesn't come out the right way," he says, "you're going to get trashed."

There is evidence to support that charge. In 2009 *Nature* detailed the backlash to a reasonably solid study published in the *Proceedings of the National Academy of Sciences USA* by researchers from Loyola University Chicago and the University of Notre Dame. The paper showed that GM corn seemed to be finding its way from farms into nearby streams and that it might pose a risk to some insects there because, according to the researchers' lab studies, caddis flies appeared to suffer on diets of pollen from GM corn. Many scientists immediately attacked the study, some of them suggesting the researchers were sloppy to the point of misconduct.

A WAY FORWARD

THERE IS A MIDDLE GROUND in this debate. Many moderate voices call for continuing the distribution of GM foods while maintaining or even stepping up safety testing on new GM crops. They advocate keeping a close eye on the health and environmental impact of existing ones. But they do not single out GM crops for special scrutiny, the Center for Science in the Public Interest's Jaffe notes: *all* crops could use more testing. "We should be doing a better job with food oversight altogether," he says.

Even Schubert agrees. In spite of his concerns, he believes future GM crops can be introduced safely if testing is improved. "Ninety percent of the scientists I talk to assume that new GM plants are safety-tested the same way new drugs are by the FDA," he says. "They absolutely aren't, and they absolutely should be."

Stepped-up testing would pose a burden for GM researchers, and it could slow down the introduction of new crops. "Even under the current testing standards for GM crops, most conventionally bred crops wouldn't have made it to market," McHughen says. "What's going to happen if we become even more strict?"

That is a fair question. But with governments and consumers increasingly coming down against GM crops altogether, additional testing may be the compromise that enables the human race to benefit from those crops' significant advantages. SA

MORE TO EXPLORE

Food, Inc.: Mendel to Monsanto—The Promises and Perils of the Biotech Harvest. Peter Pringle. Simon & Schuster, 2003.

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SCIENTIFIC AMERICAN ONLINE

Watch a video on how genetically modified crops are made at ScientificAmerican.com/sep2013/gmo