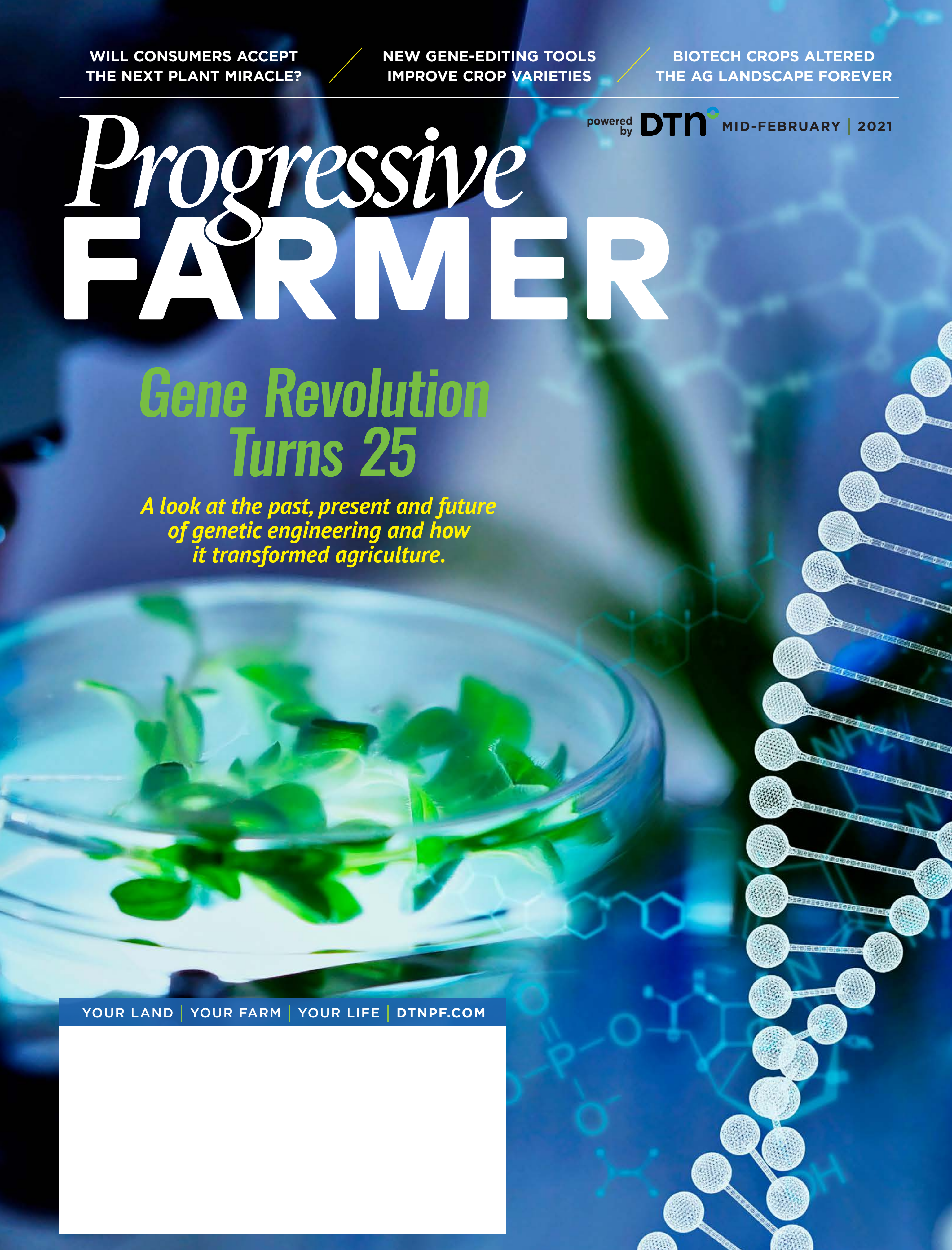

WILL CONSUMERS ACCEPT THE NEXT PLANT MIRACLE?

NEW GENE-EDITING TOOLS IMPROVE CROP VARIETIES

BIOTECH CROPS ALTERED THE AG LANDSCAPE FOREVER

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Progressive FARMER

Gene Revolution Turns 25

A look at the past, present and future of genetic engineering and how it transformed agriculture.

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Gregg Hillyer
Editor In Chief

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A Gene Revolution

Ever since Austrian monk Gregor Mendel's work with pea plants in 1866 revealed how plant characteristics are passed from generation to generation, scientists have been editing the genetic code of organisms to produce progeny that's better than the previous generation. What has changed through the years are the tools and methods they now possess to do their work.

Nothing has been more transformational than genetic engineering. The ability to insert the DNA of one organism into another so the recipient expresses the trait encoded by that gene helped launch the biotechnology revolution in agriculture.

U.S. farmers quickly embraced genetically modified crops when commercially introduced in 1996. They were thrilled with the ease of use and the level of pest and weed control from planting transgenic crops with Bt insect resistant and herbicide-tolerant traits.

Today, America's farmers plant 88% and 82% of cotton and corn acres, respectively, with Bt technology. Herbicide-tolerant crop acres are even higher: 95% cotton, 94% soybeans and 89% corn.

Some 39% of the world's crop acres planted to genetically modified (GM) traits are in the U.S. Other countries with notable adoption of GM crops include Argentina, Brazil, Canada and India (see map). Globally, 48% of soybeans are GM, 32% corn, 14% cotton and 5% canola.

The past 25 years have seen further advances in the science and potential products of genetically altered plants and animals. But, ongoing censure leaves the technology's reputation tarnished in the eyes of its critics.

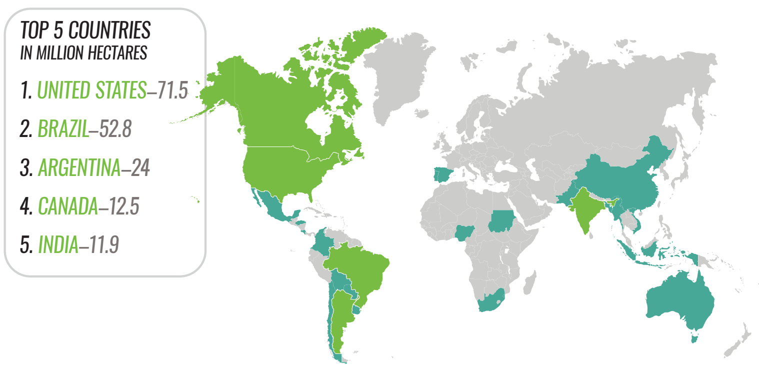
The first generation of commercial transgenic traits centered solely on farmer benefits. Consumers were left with questions and concerns about the safety of using the technology to fiddle with their food. In turn, the ag industry did a poor job explaining the benefits of genetically altered plants for consumers.

Critics and anti-GM groups sowed further doubt. Outside the U.S., countries (Europe, in particular) took action by prohibiting the planting of GM crops. Multiple groups opposing GM also can be found in the U.S.

This special issue looks at some of the highs and lows of the gene revolution in agriculture, and provides historical perspective on biotechnology, past, present and future. While the issue only focuses on crops, gene-editing technologies are being used in livestock, as well.

What will the next 25 years bring for biotechnology in agriculture? Time will tell. But, it's critical the industry is transparent in telling the public how GM technology works and the potential benefits it can bring to food security, sustainability, the environment and more. Only then will the full advantages of the science be realized, not only in the U.S. but around the world.

WHERE GM CROPS ARE GROWN



EDITOR IN CHIEF

BY *Pamela Smith*

GENE-ALTERED ATTITUDES

Will consumers accept the next round of plant miracles?

Roger Beachy still remembers the excitement of planting the first genetically altered food crop into United States soils. It was the summer of 1987 when he, along with a team of Monsanto scientists, transplanted tomatoes modified to resist a virus at the company's research farm, near Jerseyville, Illinois.

"I believed we were seeding hope for a hungry world. We were working toward ways to reduce dependence on chemicals," says Beachy, then a scientist at Washington University, in St. Louis, Missouri.

It would take almost a full decade before transgenic plants gained a serious foothold in U.S. soils, and they would not be those the idealistic young scientist envisioned. Instead, corn, cotton and soybeans designed to resist pests and herbicides hit pay dirt, and the seed and chemical industry became entwined, creating a tsunami of changes throughout the private and public agriculture sectors.

BITTERSWEET MEMORIES

Iowa farmer Bill Horan becomes almost giddy remembering the first days of Roundup Ready crops.

"It was incredible—the most amazing thing that happened in my farming life," Horan says. "Before, I spent the whole summer spraying, hoeing and trying to save my crop, and Roundup eliminated that. It allowed me time to be a better manager, a better husband and father.

"Time is the most precious thing any human has, and this technology gave me more of it," Horan recalls. The technology also allowed less tillage and more soil-saving practices.

New genetic tools enhance many crops, such as these potatoes in the labs at Calyxt.
PHOTO COURTESY OF CALYXT

Still, consumers had little to show from these early direct-to-farmer benefits. Perceptions of science tinkering with nature, corporate secrecy, well-organized and well-funded environmental campaigns, even weed and insect resistance combined to create a public relations nightmare that haunts the technology today.

Beachy, who serves on the National Science Board, calls the rejection of the science and increased regulatory requirements that resulted "arrogance of plenty." Cutting-edge tools that could have improved quality of life for many through vitamin-enhanced food, for example, are only now starting to be realized some 30 years later, he notes.

SECOND-GEN DISCUSSIONS

Gene-editing techniques now allow plant breeders to make specific and targeted improvements to a plant's genome blueprint, and promise to provide more consumer benefits than the commercialized first-generation transgenic technologies. Will consumers be more willing to swallow low-gluten wheat that sidesteps sensitivities or sip coffee that has been saved from devastating disease?

Jim Blome, Calyxt chief executive officer, believes more information-sharing and transparency about the very definition of gene editing should help make the technology more palatable. Calyxt's heart-healthy, high oleic oil cleared regulatory hurdles in 2019 and became the first gene-edited food to reach market.

"In gene editing, we're not adding new chapters to the book. We're just editing the words in the chapters that are already there," Blome explains.

Jennifer Kuzma, professor and co-director of the Genetic Engineering and Society Center at North Carolina State University (NCSU), says history has shown how important it is to instill public confidence and lift the veil on how plants or plant products are modified.

USDA's SECURE (sustainable, ecological, consistent, uniform, responsible, efficient) rule, enacted in 2020, is expected to exempt gene-edited plants from USDA premarket field testing and data-based risk assessment if they meet specific criteria.

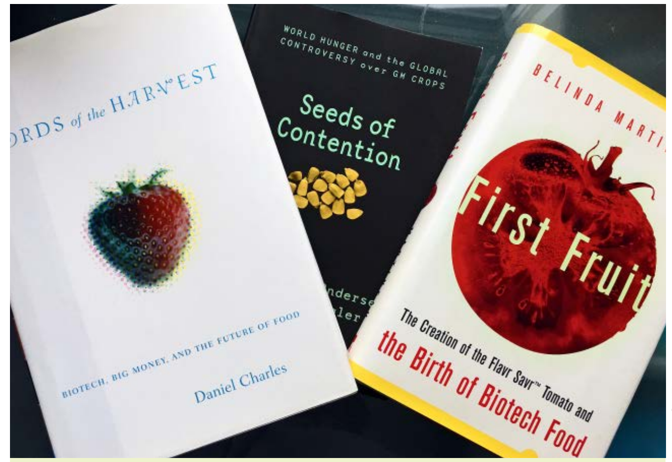
"Consumers want to know which products are genetically modified and which are not. I don't expect that to change for gene-edited crops," Kuzma says. "Crop developers, including companies, have signaled they want to do a better job with gene editing to improve public trust.

Scientists Roger Beachy and Robb Fraley plant the first biotech food plants at Monsanto's Illinois test farm in 1987.
PHOTO COURTESY OF BAYER

"If we simply say gene editing is a new breeding technique, and that we need it to revolutionize food and agriculture and that it provides benefits to the planet…that's much the narrative formed in the early days of GMOs. We need to be informed by past communication mistakes to present a better future," she says.

In a recent *Science* article, Kuzma and her colleague, Khara Grieger, assistant professor at NCSU, recommended a framework for a non-profit coalition that would provide open access to information on all biotech crops in layman's language.

Sustainability and climate change will be big drivers in altering attitudes, Blome believes. "We have to do a better job of explaining these benefits and the extensive review and selection steps gene-edited products go through prior to market launch," he says. ///



PAMELA SMITH

READ MORE: HISTORY MATTERS

The early days of genetic engineering became mired in a mix of competition, politics and activism. As new foods derived from next-generation gene editing come to market, there's caution in the familiar words of philosopher George Santayana: "Those who cannot remember the past are condemned to repeat it."

Find a good grounding in the story of how biotech crops came to be in "Lords of the Harvest: Biotech, Big Money, and the Future of Food," by Dan Charles, a science reporter and correspondent for National Public Radio.

The copyright may be 2001, but Charles' book holds up as a record of the people and events that have shaped the technology.

"I came at the subject at a good time," says Charles of his ability to gain candid disclosure from commercial firms and pioneering scientists, both private and public. "The scientific community at that time were very open to talking about it [genetic engineering] as sort of a scientific triumph. That might not have been possible when things got bogged down later in more angry arguments."

Beyond traditional row crops, readers learn more about early failed attempts to bring genetically engineered innovations such as bacteria designed to prevent ice formation on strawberries and traits that delayed ripening in tomatoes. Belinda Martineau's book "First Fruit" digs deeper into the birth and brief, two-year life span of the slow-to-rot Flavr Savr tomato, which was the first engineered food to be commercialized in the United States.

Read more about the technology risks and benefits for developing countries in "Seeds of Contention: World Hunger and the Global Controversy over GM Crops," by Per Pinstrup-Andersen and Ebbe Schioler.

To explore other titles and discuss views about biotechnology, food and agriculture, check out the weekly Twitter chat **@AgBookClub**.

BY Matthew Wilde

DESIGNER CROPS

CRISPR's genetic scissors slice through crop problems to improve varieties.

Tom Oswald got chills the first time he heard about CRISPR technology. It was 2015, and the Cleghorn, Iowa, farmer immediately began to dream of genetically engineered soybeans that would address white mold—a periodic problem on his farm—as well as other disease and pest problems.

CRISPR stands for clusters of regularly interspaced short palindromic repeats. It's just one of several gene-editing tools—ranging from GM (genetically modified) techniques to technologies that engineer enzymes to cut specific sequences of DNA—changing crops of the future.

It allows researchers to precisely find and alter DNA sequences inside a cell or modify gene function by turning them off and on without altering their sequence. CRISPR can transform plants to make them more resilient and productive, and correct genetic defects, among other things.

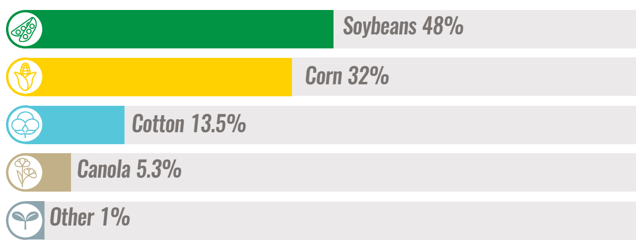
The key to CRISPR is the multiple types of "Cas" (CRISPR-associated) proteins found in bacteria that can be programmed to act like a pair of molecular scissors, capable of precisely cutting strands of DNA within the same species. (In comparison, GM technology cuts and pastes genetic material from one species into another. Since CRISPR isn't used to introduce foreign genes in a plant, some scientists argue it shouldn't fall under the same rigorous regulatory process as GM-derived plants.) The Cas9 protein is the most widely used by scientists, according to **newscientist.com**, which can be programmed to find and bind to almost any desired target sequence. This occurs by giving the enzyme a piece of RNA (ribonucleic acid) to guide it in its search.

Iowa farmer Tom Oswald believes CRISPR technology will improve plant resilience.

MATTHEW WILDE

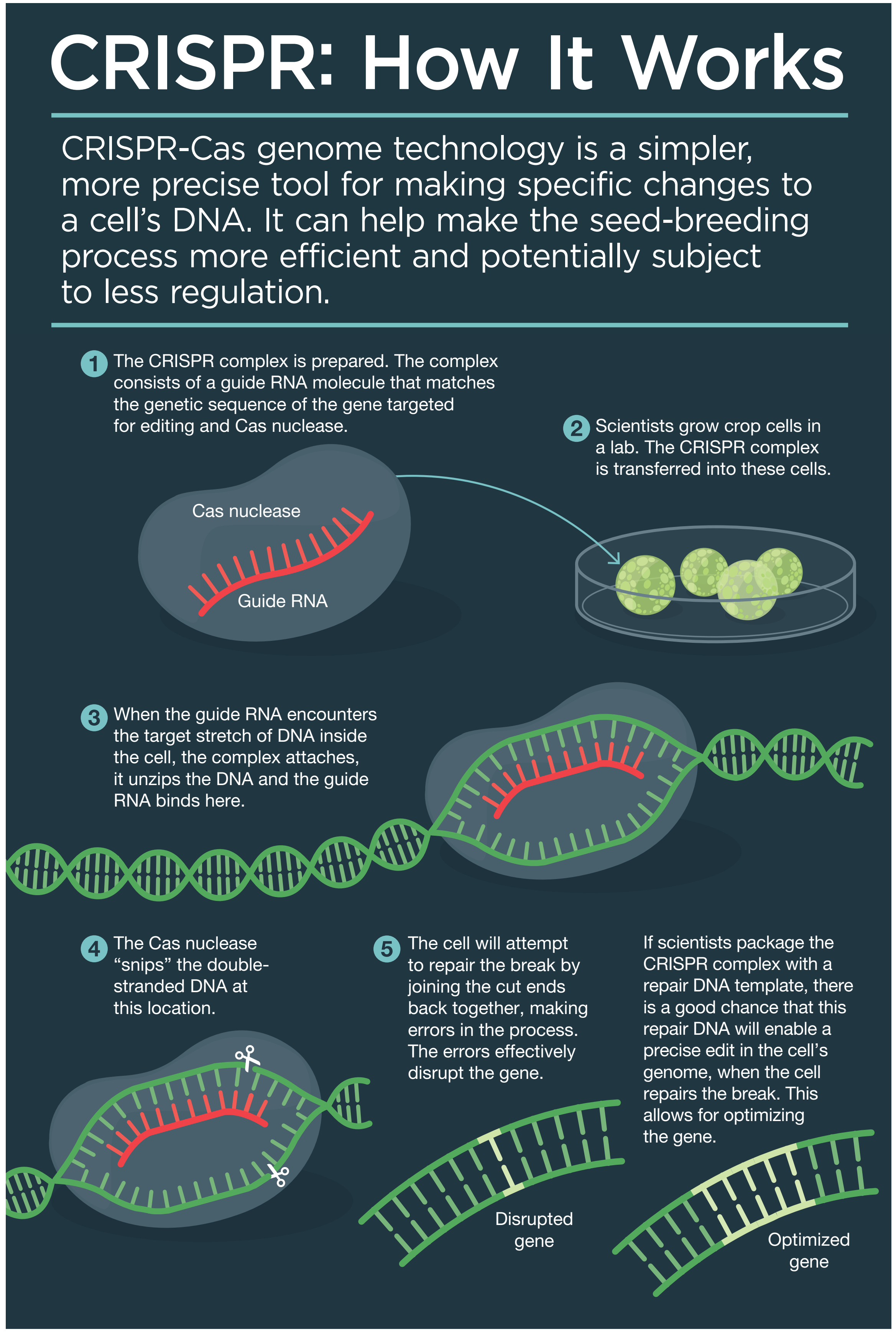
Seed chipping lets scientists analyze crop variants created through CRISPR.
BAYER CROP SCIENCE

WORLDWIDE ADOPTION OF GM TECHNOLOGY IN SELECTED CROPS



Oswald, a corn and soybean farmer and United Soybean Board (USB) executive committee member, first heard about CRISPR during a presentation in 2015. USB contributed funds to map the soybean genome, an important step in using CRISPR to transform soybean plants. Oswald believes CRISPR will revolutionize agriculture, specifically grain and oilseed production.

"I will never forget that presentation on CRISPR; the flash bulbs went off in my head," he recalls. "I said, 'Wow, this is the equivalent of designer crops in the sense of plant development.' ➤



ILLUSTRATIONS BY LUCY READING-IKKANDA

TECHNOLOGY HELPS SCIENTISTS WIN NOBEL PRIZE

CRISPR was first discovered in 1987, according to the American Society for Microbiology. It was recently thrust into the spotlight when scientists Emmanuelle Charpentier, of Germany, and Jennifer Doudna, of the United States, won the 2020 Nobel Prize in chemistry. They discovered the CRISPR/Cas9 genetic scissors in 2012, which propelled use of the technology.

It's now possible to change the DNA of plants, animals and microorganisms with extreme precision over the course of a few weeks, Nobel officials proclaim.

"There is enormous power in this genetic tool, which affects us all," says Claes Gustafsson, chair of The Nobel Committee for Chemistry, in a press release. "It has not only revolutionized basic science but also resulted in innovative crops and will lead to ground-breaking new medical treatments."


GETTY IMAGES

CRISPR AND SEED CHIPPING

CRISPR and seed chipping go hand in hand when it comes to developing new seeds and traits, explains Jonathan Phillips, head of weed and pest control research in plant biotechnology for Bayer Crop Science.

Seed chipping involves slicing off a tiny piece of an individual seed—mostly corn, soybeans, cotton and vegetable crops—to undergo DNA analysis. The seed remains viable so it can be grown in breeding trials.

GETTY IMAGES

As new crop variants are created via CRISPR, chipping allows researchers to analyze the variation in the seed to determine whether it should be field tested.

"Seed chipping allows us to track [genetic] changes efficiently," Phillips says.

"Researchers will be able to figure out ways to mitigate evolving problems, such as with pests, much quicker by making a small, incremental change without breeding plants for a decade to correct it," Oswald continues. "That will reduce economic damage to farmers."

AGRICULTURAL USE

CRISPR is already an established tool for commercial seed companies' breeding efforts. Bayer Crop Science uses CRISPR technology to discover how genes work within plants and develop new commercial products.

Jonathan Phillips, Bayer Crop Science head of weed and pest control research in plant biotechnology, says: "I don't see CRISPR playing a role so much in weed and pest control. I see it improving nutritional benefits of crops, industrial uses, altering crop architecture and improving crop efficiency and drought tolerance. Traits that are already intrinsic to the plant and making them better."

Corteva Agriscience considers CRISPR an evolution of breeding technology. The company's researchers use it to efficiently and effectively create new variations of crops that will be meaningful to growers, explains Tom Greene, global leader of trait discovery. The company is developing waxy corn lines using CRISPR.

He foresees improvement in crop production, disease resistance, stress tolerance, output traits such as protein content and plant resilience because of CRISPR. Cas9 is the company's "workhorse" protein when utilizing the technology.

To develop new variations of disease-resistant crops, for example, Corteva scientists often leverage dominant disease resistance from tropical (South America) germplasm and cross the improved resistance into temperate (North America) germplasm. Greene says that's a hard cross to make, which takes a lot of time, energy and money to clean up backgrounds using traditional marker-assisted breeding processes.

"With CRISPR, we now have the ability to mine our deep sequencing knowledge of tropical germplasm, pull out a single gene that's driving disease resistance and precisely put it in the same location of the temperate germplasm," Greene says. "It allows us to create more efficient, high-performing products for growers faster."

Corteva has new products and traits generated by CRISPR in its development pipeline, but none have been commercially released. ///

FOR MORE INFORMATION:

www.cropscience.bayer.com
www.corteva.com

BY Matthew Wilde

Scientists at Syngenta use multiple technologies to improve crop yields.

PRESS THE EDIT BUTTON

New tools hasten future seed and trait introductions.

Playing the role of fortune-teller, Syngenta's head of global seeds and research might foresee an exciting future for crop varieties and traits thanks to big advances in plant breeding.

"Looking into the future, transgenic technology will be accelerated by the new innovation that is happening in biotech areas, such as genome editing," Gusui Wu says. "We believe gene-editing technology will have a big impact in the years to come."

Advancements in gene editing and biotechnology are being driven by multiple seed companies in their efforts to improve agronomic attributes and yield, to name just a few.

PHOTOS PROVIDED BY SYNGENTA

Jonathan Phillips, head of weed and pest-control research in plant biotechnology for Bayer Crop Science, predicts researchers have only scratched the surface of gene editing. He predicts the big change going forward is how new technology and traits are deployed.

Tom Greene agrees. The global leader of trait discovery with Corteva Agriscience says plant transformation and gene editing will continue to evolve.

"I think we will continue to see an evolution of molecular-based technologies that target genome modification in different ways. Improvements in the efficiency of moving large sequences of DNA to enable the improvement of alleles from one background to another will facilitate trait development," he says.

"Researchers will continue to look at efficiencies of different versions of CRISPR technology [see "Altered Plants," on page 10] and base-editing technology to expand the utility of these technology platforms."

HI-EDIT

At Syngenta, Wu contends HI-Edit technology, which the company recently patented, is the next big thing in plant transformation and trait development. HI-Edit is short for haploid-induction editing. Wu says it could reduce the time to develop commercial hybrid varieties by 70%.

HI-Edit combines genome-editing technology such as CRISPR-Cas9 with the reproductive process of haploid induction (HI) that occurs naturally in hybrid crops such as wheat, corn and barley. Breeders can modify crops at various stages during the seeds research and development process without the substantial cost and time associated with trait introgression, the traditional method of transferring desirable genes from one crop variety to another. That can take up to seven or more years to fully complete, according to the company.

Using corn as an example, here's how HI-Edit works:

- Haploid induction allows pollen from one genetically modified plant to carry CRISPR-Cas9 components into another plant's reproductive cells.
- Gene editing occurs during the fertilization process.
- The progeny will have the result of the editing but not the editing components. The CRISPR-Cas components will no longer be detectable in the offspring, because they are left behind and destroyed in the haploid formation process.

Wu says HI-Edit technology can be used to bring gene-edited traits, such as disease resistance, drought tolerance and other agronomic traits, to corn or other hybrid crops ultimately improving yield gain. And, it can be done in one generation of breeding, he adds.

"With HI-Edit, I just need to make one cross of my transformed gene-edited line with an elite inbred variety," Wu continues. "It accelerates the time to market for future traits. HI-Edit is a game changer."

In the future, he says HI-Edit will likely help transform nonhybrid crops, as well.

PROBLEM-SOLVER

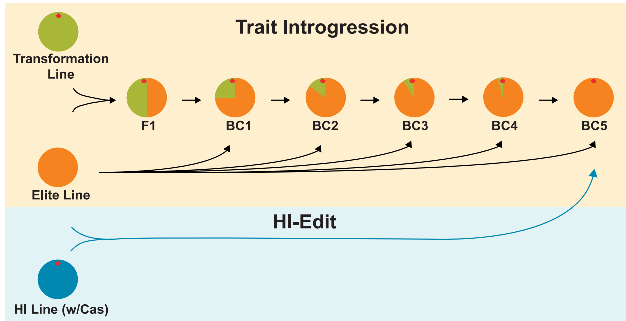
Wu indicates HI-Edit could be used to help mitigate challenges farmers face today in crop production. For example, Syngenta researchers are working on herbicides with new modes of action to help farmers battle herbicide-resistant weeds.

"HI-Edit will allow us to put a trait in plants of elite [germplasm] genetic background to allow them to tolerate a new herbicide in rapid fashion," he explains. "We're also developing a new generation of herbicide tolerance and insect-control traits. In the future, we won't be deploying them the same way we are today because of HI-Edit."

Syngenta is working on multiple projects involving HI-Edit, such as maturity modification and plant architecture (plant shape and height, ear height, etc.). Wu can't predict when new products developed with HI-Edit will be ready for market because they're still in the pipeline, and the regulatory procedure process for gene-edited crops is a work in progress.

Regulatory approval for gene-edited crops using HI-Edit may be easier, because the method doesn't involve putting the CRISPR genes into the DNA of the resulting crop. That makes it indistinguishable genetically from the preexisting, naturally occurring variety. ///

SYNGENTA'S HI-EDIT TECHNOLOGY



Syngenta's HI-Edit gene-editing technology will reduce the time it takes to get new traits to market.
PROVIDED BY SYNGENTA

FOR MORE INFORMATION:

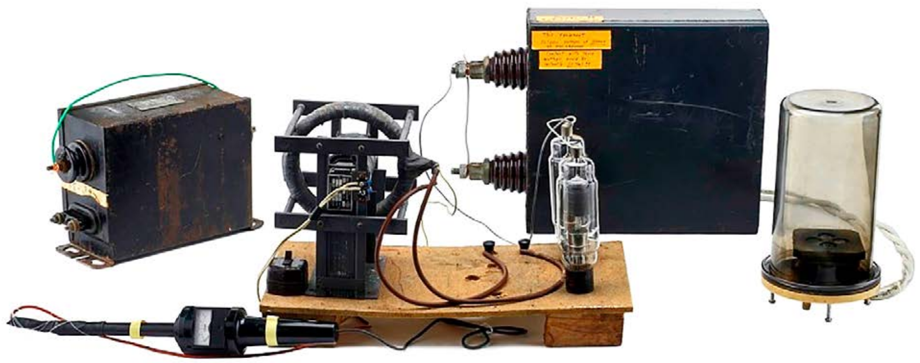
- www.syngenta-us.com
- Follow Matthew Wilde on Twitter @progressivwilde.

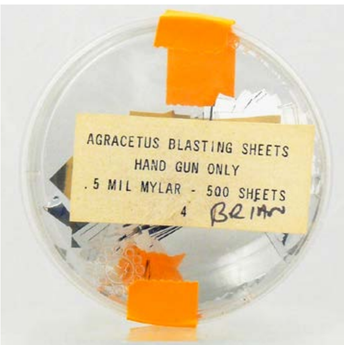
BY *Matthew Wilde*

SHOT HEARD AROUND THE WORLD

Gene gun helped to ignite agriculture's biotechnology revolution.

A plywood-mounted transformer, a voltmeter-equipped wand and a pair of bulbous vacuum tubes might appear to be just a random collection of components. But, Brian Martinell and Dennis McCabe turned them into a tool that would revolutionize plant breeding and help usher in genetic engineering in agriculture. Their gene gun prototype (above) is now displayed at the Smithsonian's National Museum of American History.





Blasting sheets from a gene gun developed by Agracetus

PHOTOS: SMITHSONIAN INSTITUTION

The Agracetus researchers invented the device in 1986, and it played an integral role in the development of Roundup Ready soybeans and biotech crops.

The duo drew inspiration for their work from Cornell University geneticist John Sanford, who, a few years earlier, used a tungsten-loaded .22-caliber pistol to fire foreign DNA-coated microbullets into raw onions to create transgenic plant cells. Scientists were also experimenting with Agrobacterium at the time to insert DNA into plant cells. That had limited success on some plant species in the early 1980s, but not in commodity crops such as soybeans, corn, rice and wheat.

BRILLIANT IDEA

Agracetus, an ag research company in Middleton, Wisconsin, was working on plant transformation in the 1980s. Martinell recalls colleagues laughing when they heard of Sanford's work. But, not McCabe. "Dennis looked at me and said, 'That's brilliant!'"

McCabe and Martinell fashioned their own version of a gene gun in 1986 from scrapped radar station parts McCabe purchased years earlier from the University of Iowa. It consisted of a plywood-mounted transformer, a voltmeter-equipped wand, a pair of vacuum tubes, wires and a 15,000-volt capacitor. "Danger—High Voltage" signs were hung on and near the contraption, along with a handwritten sticker saying, "Contact with these voltages could be instantly lethal!"

The first prototype didn't have switches, so the scientists manually touched wires to electric terminals to create a high-voltage shock to transform a water droplet into a shock wave that drove DNA-coated microparticles of gold into plant tissue. Blinding flashes of light and explosions accompanied initial experiments.

"It only took a couple days to put the gene gun together to get the first spark discharge, but it took a couple months to get something that didn't explode," Martinell says. "Truth be told, it was extremely dangerous and fatal if you made a mistake. But, we were young and did crazy things. We took risks and didn't worry about it."

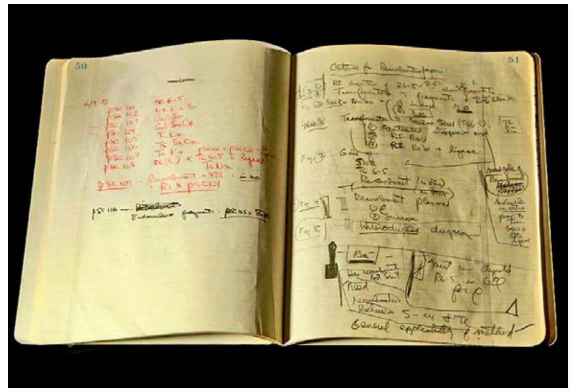
Subsequent versions of Martinell and McCabe's electric gene gun became much safer, but the basic principle remained the same. By 1988, they used the gene gun to create the first genetically modified soybeans by bombarding exposed meristems with DNA-coated gold particles.

DONE DEAL

Monsanto heard about Agracetus' success and came calling. Martinell recalls the day Winston Brill, founder and president of Agracetus, signed the $5 million contract with Monsanto to develop Roundup Ready soybeans.

"Winston came into our lab saying he was ready to sign the document and asked, 'Do you really think this … works?'" Martinell says. "I remember distinctly Dennis and I looking at each other and looking back saying, 'Yep.'"

Robb Fraley, former executive vice president and chief technology officer at Monsanto, helped the company develop a strain of bacteria containing genes that would make plants resistant to glyphosate, the active ingredient in Roundup herbicide. Even though Monsanto was working with Agrobacterium to deliver genes of interest into host plants, Fraley indicated the Agracetus gene gun was more efficient at inserting the glyphosate-resistance gene into soybean plants at the time.



SMITHSONIAN INSTITUTION

Handwritten notes by Stanley Cohen, a pioneer in the field of genetic engineering

Monsanto produced the first Roundup Ready soybeans in 1989, which were commercialized seven years later.

"The gene gun was one of the first useful tools for plant transformation," Fraley explains. "It was surprising to think you could stick genes on gold particles that could be shot into cells, but the results were compelling."

RIGHT TECHNOLOGY, RIGHT TIME

In the 1980s and early '90s, farmers struggled to control weeds. Roundup was effective but couldn't be broadcast-sprayed in-season without killing the crops.

BRIAN MARTINELL

Early use of the Agracetus gene gun prototype was wrought with danger.

"We knew Roundup Ready crops would be important to farmers, but no one expected it to be so popular," Fraley says.

Farmers such as Don Willis, Hillsboro, Tennessee, quickly adopted the technology. Today, more than 90% of soybeans, corn, cotton and canola grown in the U.S. include the glyphosate-resistant trait.

Willis says it was a "no-brainer" to plant Roundup Ready soybeans, which he could spray once or twice, and have clean fields.

"Our soybean yields went up in a hurry and it [weed-control program] was easy," Willis says.

Peter Liebhold, curator of the Division of Work and Industry at the National Museum of American History, in Washington, D.C., says the Agracetus gene gun is an important part of agricultural history.

"This is the beginning of GMOs (genetically modified organisms)," Liebhold says. "In history, you often have incredible moments. Finding an artifact that really connects is difficult, but to me, this is that piece."

For Martinell, the gene gun represents something more. "I remember a farmer friend came to me [shortly after Monsanto introduced Roundup Ready soybeans in 1996] and said, 'I just want to say thank you. You've made my life easy,'" he recalls. "That was so cool, knowing something I helped with was in the field." ///

FOR MORE INFORMATION

on the Agracetus gene gun:
www.americanhistory.si.edu/collections/search/object/nmah_1165091

➤ Follow Matthew Wilde on Twitter **@progressivwilde**.

BY *Des Keller*

WHY DOES EUROPE OPPOSE GMOs?

Hostility over transgenic technologies remains strong with little progress to find common ground.

GETTY IMAGES

In a country where genetically modified organism (GMO) crops are planted on millions of acres, most Americans don't understand why so many in Europe are opposed to the technology. There is no simple answer.

It's somewhat ironic that nearly an entire continent contests GMOs since Belgium scientist Marc Van Montagu is often referred to as the father of plant biotechnology. Regardless, Europe's anti-GMO stance has long been shaped by social and cultural norms, along with a politically strong "green" movement and a regulatory process that lacks public confidence.

Those who support the use of transgenic crops and related plant-breeding technology are often left in a quandary.

Agronomy grad student Frederik Vilhelm Larsen, at the University of Copenhagen, Denmark, wants to explore all the science that can potentially help farmers. But, for now, focusing research on GMO technology is largely put aside because it can't be used by farmers there.

"Like everything else, GMOs can be a powerful tool to help with difficult situations farmers face," says Vilhelm Larsen, 26, whose family farms 520 acres two hours from Copenhagen. "The negative attention comes from overusage of the same herbicide tech and corresponding emergence of herbicide-resistant weeds, which risks increases in total herbicide usage."

As a result, additional GMO benefits like crops containing Bt that fight crop pests and diseases aren't given their due. "Everyone likes a crop that can take care of itself," he says. Larsen's family grows winter wheat, barley, rapeseed (canola), grass seed and fava beans.

In 2015, a European Commission rule was passed that gave EU countries the ability to opt out of growing GMO crops even though many countries already had a de facto ban in place. Nineteen countries chose not to grow GMOs, with the major ones being Austria, France, Germany, Greece, Italy, Poland and Scotland.

CRISPR CONTROVERSY

There are countries other than those in the EU that oppose GMOs. For example, a moratorium on GMOs exists in Russia through 2023. However, Europe is one of the world's biggest trading blocks. European countries are major allies of the U.S., and their members have been international leaders in the environmental and "green" movements, many whose platforms are anti-GMO.

A significant battle happening now is about whether the new CRISPR technology that can "edit" genes within a plant will be considered a GMO or is in an approvable category of its own. CRISPR is already being used on crops like cherry tomatoes (larger fruit/disease resistance) and mushrooms (resistance to browning). CRISPR is a very precise way of altering or deleting existing DNA to obtain a desired outcome. The process differs from more traditional transgenic modifications that use genetic material from other plants, bacterium or animals to create a desired trait. (See "Designer Crops," on page 10.)

"In general, I hope the CRISPR technology or some versions of it could be seen as non-GMO technology and would advance conventional breeding for all of the ag sector," Vilhelm Larsen says.

The EU has been importing GMO soybeans from North and South American for several years, exempted because the crop is needed for livestock feed. Despite this, the majority of the EU countries have been adamant in opposition to growing GM crops. A Pew Research Center international survey in 20 countries (including the U.S.), conducted from fall 2019 through March 2020, found that overall, 48% of respondents view GMO foods as unsafe to eat as opposed to 13% who believe they are safe. Results varied by country. Nearly 70% of Russians surveyed believed GMO foods were unsafe, while in the U.S., that number was 38%.

CONSUMER UNCERTAINTY

In addition to Russia, those countries with the highest percentage of respondents who believed GMO foods were "generally unsafe to eat" were Poland (67%), Italy (62%) and India (58%). Some of the countries with the highest number of respondents who believed GMO foods were safe to eat were Sweden (38%), the U.S. (27%), Canada (27%) and India (26%).

In nearly all the countries, there were significant numbers of respondents who said they didn't "know enough to say" to make a judgment on the issue. In Japan, 51% of those surveyed said they didn't know enough to determine whether GMO foods were safe to eat. The percentages were similarly high in the Netherlands (50%), the UK (46%), Singapore (44%), and Spain (39%). In the U.S., 33% of respondents said they didn't know enough to make a determination.

This uncertainty contrasts sharply with general scientific studies, which have determined on numerous occasions that foods derived from GMO crops are safe. Most importantly in the U.S., the National Academies of Science, Engineering and Medicine have weighed in, issuing a report on the topic in 2016 agreeing that GMO crops and products made with them are safe.

Still, the stigma against GMO crops remains and can even affect how scientists perceive their work and careers. Devang Mehta, a native of Bombay, India, who received a Ph.D. in plant biotechnology from the research university ETH Zurich, in Switzerland, essentially moved from direct GMO research involving cassava into more basic plant biology research at the University of Alberta, in Canada.

"I had worked on the tropical plant, cassava, which feeds about a billion people worldwide," says Mehta, who was interested in using technologies like CRISPR to reduce viral diseases in the plant. "It wasn't so much that I experienced backlash personally; it was more like I'd be at a dinner party with other scientists and tell someone what I did, and be met with a kind of silence or negative comments about the technology."

Other Ph.D. students in Zurich working on GMO crops have had research fields destroyed by activists. At other times, paint has been splashed on researchers' cars, Mehta explains.

"I'm also glad to be moving away from transgenic research," Mehta wrote in an article for digital media company Massive Science and syndicated on Slate, "because anti-GMO activism over the last couple of decades has made a career in GMO research a risky proposition." ➤

The condemnation of GMOs from European farmers isn't universal. Martin Mogensen, whose Danish family farms 2,400 acres of wheat, barley, canola and grass seed while keeping a 1,000-sow operation, would like more options.

"As I see it, the green agenda in Europe wants us to use less chemistry but doesn't want us to use the tools that would get us there faster," he says. Technology like CRISPR would be a huge step forward. Particularly, he explains, plants that could resist fungi would be more valuable than plants that resist any herbicide.

Some European countries do grow specific GMO crops. The Czech Republic, Portugal, Slovakia and Spain are among them. In 2019, The Danish Council on Ethics recommended updating its laws to allow some genetic modifications to be used. Council members said at the time that plant modifications can help crops deal with the effects of climate change, which is fostering an increase in pest and disease infestations. The recommendations haven't yet resulted in any changes in the country's (or EU) laws.

ONGOING OPPOSITION

French farmer Rémi Dumery works 400 acres of durum wheat, barley, sugar beets, corn, soybeans and canola in the central part of the country, near Orleans. He says he would like more tools such as GMO traits but isn't optimistic that will happen in the near future.

"There is a paradox in France," Dumery explains. "People refuse genetic manipulation techniques on plants, but a recent telethon collected millions of euros in donations to carry out genetic manipulation to cure myopaths [diseases such as muscular dystrophy]. Genetics are one of the keys to our food and energy production in a renewable mix."

Initially, Dumery says, EU farmers believed they would get a premium by remaining non-GMO, but that added value has generally been captured by distributors and has not trickled down to farmers. As in Denmark, he sees glimmers of hope if genetic manipulation can overcome serious vexing issues facing some crops.

"Hope may come from the sugar beet jaundice crisis," Dumery believes, "if NBT [new breeding technologies] techniques can create varieties resistant to jaundice viruses and dispense with neonicotinoids [a class of insecticides] within three years."

France tested some GMO corn into the early 2000s until protests resulted in a ban. Much of the anti-GMO sentiment is believed to be the result of the strength of environmental activist non-governmental organizations and the Green Party, particularly in Germany. Additionally, mad cow disease scared much of the public, with governments and the EU taking different positions on the safety of beef. Consumers remained uncertain and fearful.

Rémi Dumery isn't optimistic he will be able to plant transgenic crops anytime soon on his farm in France.

D. CHAUVEAU, PROVIDED BY RÉMI DUMERY

Many in the EU likely fear the situation where a crop containing GMOs would be uncontrolled inside and outside of farm fields, explains Danish agricultural journalist Niels Damsgaard Hansen. "For a few, the opposition is merely based on using the GMO technology for Roundup Ready crops instead of other traits like resistance to disease and pests."

Hansen doesn't see EU opposition to the technology going away anytime soon. "I don't think most EU farmers find it harmful not having access to the present GMO crops," he says. "Especially considering that soya, corn and cotton are not as important in most of the EU as in the U.S. If GMO crops or CRISPR crops in the future introduce other valuable traits [that directly benefit consumers], it might be another situation." ///

BY *Emily Unglesbee*

THE GOOD, THE BAD AND THE UGLY

For better or worse, biotech crops have changed the agricultural landscape forever.

Do you remember the world before GM (genetically modified) crops?

If you're like the Rendel family, of northeast Oklahoma, each generation will answer differently. Brent Rendel, who started farming in the early 1990s, easily remembers how magical Roundup Ready crops seemed and the awe of seeing weed control shift from requiring three passes across a field with chemicals and tillage, endless scouting and multiple employees, down to as little as a single application once a year by one employee.

"It made things so much easier," he recalls. "And, as with any new technology, if it gives you an 'easy button' for farming, farmers will push that baby hard!"

Brent's nephew, Zack, who joined the family in farming in the early 2000s and branched out to his own farm in 2018, has grown up in a world where that easy button is long defunct.

PAMELA SMITH

"Zack has never farmed when glyphosate was completely effective," Brent explains. In fact, the younger Rendel oversaw a suite of herbicide-tolerant traits on his farm last year, including 2,4-D-tolerant, dicamba-tolerant and glyphosate-tolerant technologies, as well as conventional soybeans.

Is he any better off now than past generations? It's a hard question to answer.

Since the first Roundup Ready seeds and Bt cotton plants in 1996, a lot has changed. Biotech crops ushered in major farm-management changes, from smaller workforces to expanded acreage possibilities. The nation saw a shift away from conventional tillage toward more no-till or minimum-till farming, as well as the growth of the cover-crop industry. The spectrum and amount of pesticides on the landscape changed, first as biotech crops killed insects and weeds with ease, and then again as the rise of insect and weed resistance chipped away at the technology's success and endangered its future.

First Bt resistant corn on the market (above). Brent Rendel (below) flips through part of the "Farm Bible," the Rendels' decades-long log of farm inputs.

PHOTOS: ZACK RENDEL

And finally, as we enter a new decade, with new biotech tools such as gene editing on the cusp of transforming agriculture once again, the industry is faced with a growing number of consumers who are pushing back against technologies they don't trust.

THE GOOD

Gus Lorenz first planted Monsanto's newfangled cotton plants, designed to express a Bt protein called Cry1Ac, in the early '90s. The University of Arkansas entomologist was helping Southern cotton farmers battle armies of caterpillars, from tobacco budworm to cotton bollworm.

"It was pretty grim right then," Lorenz says. "Growers were spraying anywhere from nine to 12 times a season and spending $150 to $200 an acre to control worms and boll weevils." He watched with trepidation as egg masses filled the leaves, and larvae emerged on the new Bt cotton variety, called Bollgard.

"But, you'd go back a week later, and there wasn't a worm in sight—they were all dead," Lorenz recalls. "We couldn't believe it. We were so excited."

Bt traits were soon inserted into corn plants, as well. Like cotton, they steadily expanded to dominate the market; today, 88% of cotton and 82% of corn acres are Bt-traited.

For some of these pests, Bt has remained a remarkable control measure. To this day, young farmers and scientists Lorenz works with have no idea what tobacco budworms look like. Farther north, Bt traits have been so successful against European corn borer that a generation of farmers don't know how to scout for it, and non-Bt corn growers have benefited from landscape suppression of the pest.

Insecticide use for these pests naturally plummeted. An annual study from two economists, Peter Barfoot and Graham Brookes, estimates that Bt cotton and corn technology reduced insecticide use for its target pests between 1996 and 2018 by 52% in the U.S. because of widespread adoption by the country's farmers.

In the meantime, Roundup Ready crop adoption was also rising, especially in soybeans and cotton.

BRENT WARREN

Overreliance on Roundup Ready technology resulted in weeds such as waterhemp becoming resistant to glyphosate.

Today, 94% of soybeans, 95% of cotton and 89% of corn acres contain herbicide-tolerant traits. University of Georgia weed scientist Stanley Culpepper remembers how his father, Luther, went from crossing a field up to 10 times a year and plowing regularly to embracing minimum-till agriculture immediately after his first Roundup crops in 1999. "He has been 100% strip-till with cover crops since," Culpepper says.

By 2017, USDA estimated that more than a fifth of U.S. cropland was in no-till practices. The fuel and soil-erosion savings from farms pivoting away from tillage toward no-till agriculture has been a boon to the environment.

> "We became more efficient. A little bigger and a lot leaner."
> –Brent Rendel

It caused rapid changes in farm management, too, the Rendels recall. At one time, Brent was annually employing multiple employees to prescout soybean fields, spot-spray them multiple times, cultivate everything the sprayer missed and then hand-spray weed escapes in small vehicles dubbed "bean buggies." "It capped our acreage," Brent recalls. "Manpower was the limit."

During the Roundup Ready era, the farm's employee roster shrank, and acres swelled. "We became more efficient," Brent says. "A little bigger and a lot leaner." ›

PHOTOS: DAN CRUMMETT

Zack Rendel (right) and his uncle have had to move away from no-till practices on their farms (left) as weed resistance grows.

And, while it's true glyphosate use rose rapidly across the country, it replaced older active ingredients, many of them with higher toxicity profiles, notes Andrew Kniss, a University of Wyoming weed scientist who conducted an analysis of long-term trends in herbicide use in six major crops. The drop has been most stark in soybeans, where chronic and acute herbicide toxicity decreased 78 and 68%, respectively, from 1990 to 2015.

> "I've moved dollars out of labor and parts, and moved it over to seed and herbicides."
>
> –Brent Rendel

Other beneficial GM crops emerged, too. GM high oleic soybeans produce stable cooking oils without trans fats, answering a consumer need and giving much-needed premiums to growers. Enogen corn hybrids allow farmers to grow corn specifically designed to more efficiently create ethanol fuel, again at a premium.

Now, the next generation of genetic engineering promises to move more consumer- and environment-friendly crops to the forefront. USDA recently decided that gene-editing technologies, which allow scientists to snip out and substitute parts of DNA faster than ever, won't be regulated like their older biotech predecessors. That means smaller companies and institutions are starting to bring gene-edited crops to market faster than ever. Mushrooms that don't brown, drought-resistant corn and high-fiber white wheat flour are just a few of the products racing toward the farmer and consumer in the next decade.

THE BAD

While yields have increased steadily in corn and soybeans over the decades, experts are still debating how much GM traits alone have contributed to that rise. For the Rendels, the greatest yield jumps on their farm have come in sorghum fields, where no GM traits exist, Brent says.

And, when the Rendels look at their current weed control and seed costs, it can be hard to see how GM crops benefited them in the long run. "I'm not sure it's made things more profitable," Brent says. "My net income hasn't changed on a relative scale. I've moved dollars out of labor and parts, and moved it over to seed and herbicides."

The primary culprit? Weed resistance.

"We noticed it was taking certain weeds longer to die, and that others were coming back quicker from applications," Zack recalls of his time on the farm between 2003 and 2005. "We didn't realize what it was we were seeing, and we were told to just keep upping the rates of glyphosate, just pouring more on, when we should have been switching chemicals."

By 2006, Culpepper had confirmed the country's first glyphosate-resistant Palmer amaranth plant, a biological superspreader of a species. "We've had herbicide resistance in agriculture for longer than I've been here, but most of the resistance we saw before this didn't change the world of agriculture," he says.

The International Survey of Herbicide-Resistant Weeds now estimates that 165 weed species are herbicide-resistant today in the U.S. alone. At least one weed, waterhemp, is now capable of tolerating six different herbicide modes of action in certain populations. Even the advent of traits with tolerance to older herbicides, such as dicamba resistance and 2,4-D resistance, hasn't slowed the march: After just four years of dicamba-tolerant crop acreage, Tennessee scientists confirmed dicamba-resistant Palmer amaranth in 2020, with 2,4-D resistance suspected, as well.

For many public scientists, tracking this resistance has become a full-time job. And, for many farmers, weed resistance has rolled back the clock on conservation tillage and increased herbicide use.

> "If we could go back 30 years, could we have done it differently?"
>
> –Stanley Culpepper

"Iron is coming back; there's no way around it," says Brent, whose operation has reincorporated conventional soybeans and tillage into its weed-management practices. "I will never have a new herbicide mode of action in my farming lifetime, nor will any other farmer in their mid-50s or above," he predicts.

In the meantime, seed costs continue to rise. The Rendels recently discovered they could grow a non-GM soybean line from the University of Arkansas that costs $30 to $40 less per unit, yields competitively with their herbicide-tolerant soybean varieties and sells for a premium.

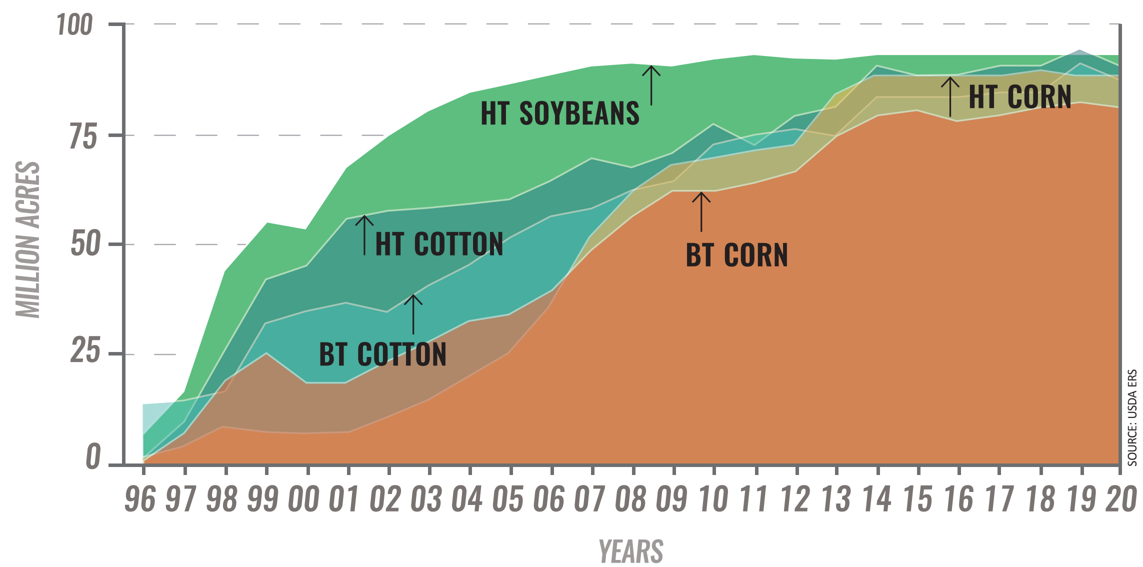
Even in Bt crops, where the insecticide reductions remain a bonus, resistance and a changing pest spectrum have dulled the technology's initial shine, Lorenz notes. In cotton, pests rushed to fill the vacuum as caterpillar control improved, he recalls. Tarnished plant bugs, thrips and stinkbugs now top cotton farmers' list of costly pests, and insecticide resistance is growing in many of these populations. Likewise, in corn, secondary corn pests that weren't as susceptible to Bt traits, such as the Western bean cutworm, have become more prominent and costly to control.

In the meantime, the worms are fighting back against Bt. Cotton bollworm/corn earworm has slowly fed its way through the parade of Bt proteins seed companies have brought to market. Southern entomologists are watching resistance pressure mount against the lone remaining efficacious protein in corn and cotton, Vip3A. Farther north, the Western corn rootworm has evolved resistance to four Bt proteins on the market that target it, and the next generation of traits have been slow to reach market.

THE UGLY

As bad as current weed resistance is, greater dangers may lie ahead. Most recently, weed scientists at the University of Illinois have confirmed the existence of a troubling new type of resistance in weeds known as metabolic resistance.

ADOPTION OF GENETICALLY MODIFIED CROPS IN THE U.S.



Weeds with this type of resistance learn how to rapidly metabolize herbicides—regardless of their mode of action—which can allow them to survive herbicides they haven't even encountered yet. Theoretically, this type of resistance could endanger all chemical control of weeds.

Within society, an old threat to GM crops still looms: consumer sentiment. A recent survey conducted by farm and food trade groups found that while consumers have little concrete knowledge of GMOs, they also have "high awareness" and negative views of the technology. The same respondents had even less knowledge of new techniques such as gene editing but had instant negative associations with them. Anti-GM groups such as U.S. Right to Know and the Non-GMO Project, which have long targeted traditional biotech crops, have turned their sights on gene-edited products, labeling them as "GMO 2.0"

"If we could go back 30 years, could we have done it differently—could we have come out with the first GMO crop that did something like cure poor eyesight?" Culpepper wonders. "If we had done that instead of pushing these traits that appeared to only help the farmer, maybe we'd be in a different situation."

Chemophobia—a distrust and fear of chemicals—is another challenge to GM crops that was at least partially borne of industry's past sins.

Widespread use of glyphosate has made the herbicide extremely easy to find in the environment and food system. And, four years of off-target dicamba injury have fractured the agricultural industry and raised the public profile of chemical use in agriculture.

"It's clear that we're not always keeping products where they need to be," Culpepper says. "The only thing we can do, moving forward, is what we are already doing trying to do: make on-target applications."

In the meantime, the Rendels stand ready to do what farmers have done for decades: change with the times. "We'll grow whatever the market tells us to grow," Brent says. "If that's GMOs, great. But, if it's not, we can do that, too." ///

SOYBEAN FLASHBACK

A peak into the "Farm Bible," as the Rendels call their decades-old log of farm inputs, shows the changing world of soybean production before and after GM crops dominated the landscape.

Input	1995	1995* (*adjusted for inflation to 2020 dollars[1])	2020
Soybean Seed[2]	Public variety: **$11/unit** (50-lb. bag) **OR** Saved Seed: **$5/bu + $3/bu**. cleaning cost	Public variety**:** **$17/unit** (50-lb. bag) **OR** Saved Seed: **$8/bu + $5/bu**. cleaning cost	GM Soybean: **$68/unit** (140,000 seeds) Non-GM Soybean: **$26/unit** (140,000 seeds)
Herbicides	Roundup: **$47/gal.** Bicep II: **$32/gal.** Cobra: **$127/gal.** Blazer: **$62/gal.** Dual: **$63/gal.** Canopy: **$34/gal.**	Roundup: **$81/gal.** Bicep II: **$55/gal.** Cobra: **$220/gal.** Blazer: **$107/gal.** Dual: **$109/gal.** Canopy: **$59/gal.**	Roundup PowerMaxx: **$16/gal.** Bicep II Magnum: **$33/gal.** Cobra: **$190/gal.** Ultra Blazer: **$58/gal.** Dual Magnum II: **$91/gal.** Canopy: **$30/gal.**
Fertilizer	28% UAN Liquid: **$140/ton** 9-23-30 Dry Fert.: **$194/ton**	28% UAN Liquid: **$243/ton** 9-23-30 Dry Fert.: **$336/ton**	28% UAN Liquid: **$185/ton**[3] 9-23-30 Dry Fert.: **$332/ton**
Fuel[4]	Gas: **$1.10/gal.** Diesel: **$1.12/gal.**	Gas: **$1.86/gal.** Diesel**: $1.90/gal.**	Gas: **$2.21/gal.** Diesel: **$2.50/gal.**

[1]Bureau of Labor Statistics CPI Inflation Calculator, all numbers rounded to the nearest dollar
[2]Public variety soybean seed costs from 2000, not 1995, because of gaps in farm recordkeeping
[3]UAN number from 2019
[4]U.S. Energy Information Administration

GENETIC SNAPSHOTS IN TIME

Path to create faster, more precise breeding techniques is an ongoing journey.

1866
Austrian monk GREGOR MENDEL publishes important work on heredity that describes how plant characteristics are passed from generation to generation.

1919
Hungarian agriculture engineer KÁROLY EREKY coins the word ***biotechnology***.

1940
Plant breeders learn to use radiation or chemicals to randomly change an organism's DNA.

1953
Building on discoveries of chemist ROSALIND FRANKLIN, scientists JAMES WATSON and FRANCIS CRICK publish their discovery of the three-dimensional double-helix structure of DNA.

1970
JOHN E. FRANZ discovers the herbicide glyphosate.

1972
PAUL BERG creates recombinant DNA from cut-and-splice method. Nobel Prize committee recognizes discovery in 1980.

1973
Stanford biochemists HERB BOYER and STANLEY COHEN create first recombinant DNA organism.

1976
Roundup herbicide is commercialized for agricultural use in U.S. and Canada.

1977
MARY-DELL CHILTON leads a team of scientists at the University of Washington in Seattle that proves the microbe causing crown gall disease in plants develops a way to transfer a part of its DNA to the gall cells.

1983
First genetically engineered plant is reported in tobacco.

1986
Gene gun prototype offers a new way to "shoot" DNA into plants.

1987
» First field of genetically engineered food crop in a field near Jerseyville, Illinois, is tested—a variety of tomato that was modified for resistance to virus disease.

» First hint of existence of clustered regularly interspaced short palindromic repeat (CRISPR-Cas) systems discovered.

1994
Flavr Savr tomato (delayed ripening) developed to become the first genetically engineered food crop in the United States.

1996
» (Cry1Ab) Bt trait in corn is commercialized.

» Roundup Ready soybeans are commercialized.

» Roundup Ready canola is commercialized in Canada.

» (Cry1Ac) Bt cotton is commercialized.

» ZFN (zinc-finger nucleases) gene-editing technology is studied.

1997
» LibertyLink corn resistant to glufosinate receives approvals.

» Roundup Ready cotton is commercialized.

1998
» First documented glyphosate resistance discovered in U.S. (rigid ryegrass in California).

» Rainbow papaya featuring gene resistant to virus introduced and credited with saving papaya industry.

1999
German and Swiss scientists develop Golden Rice, fortified with beta-carotene, in an effort to combat blindness caused by Vitamin A deficiency.

2000
First entire plant genome sequenced, Arabidopsis thaliana, which provides researchers with greater insight into genes that control specific traits in many other agricultural plants.

2005
» Roundup Ready sugar beets are deregulated.

» Roundup Ready alfalfa is deregulated, but lawsuits delay nonregulated status until 2011.

2008
First documented case of field resistance to Bt confirmed in pink bollworm in cotton.

2009
» TALEN (transcription activator-like effector nucleases) gene-editing tool invented, and first patent is filed.

» Field-evolved resistance by Western corn rootworm to Bt confirmed in Iowa.

2012
Scientists develop CRISPR-Cas9 gene editing to modify specific DNA sequences.

2013
MARY-DELL CHILTON, ROBB FRALEY and MARC VAN MONTAGU are awarded World Food Prize for pioneering work in biotechnology.

2015
Innate potato designed to resist browning commercialized.

2016
» Congress passes the National Bioengineered Food Disclosure Law.

» Waxy corn, a CRISPR-Cas9 gene-edited crop, gets deregulated from USDA (not yet commercialized).

2017
Commercialization of first Arctic apple, bred to delay browning, made possible by RNAi.

2019
High oleic soybean developed with TALEN clears regulatory hurdles to become first gene-edited food commercialized.

2020 AND BEYOND
» APHIS finalizes the SECURE rule updating its regulation and oversight of biotechnology and gene-edited products.

» Pink flesh pineapple containing higher levels of carotenoids is commercialized.

» Scientists EMMANUELLE CHARPENTIER and JENNIFER DOUDNA are awarded the Nobel Prize in Chemistry for work developing CRISPR-Cas9.

» GMO labeling becomes mandatory: All retail food products with bioengineered ingredients must be labeled by Jan. 1, 2022.

There are many conflicting and overlapping dates regarding the history of plant genetic engineering. This timeline is intended as a snapshot of events. Many scientists made significant contributions. Some sources for this information include:

www.aphis.usda.gov; fda.gov; International Service for the Acquisition of Agri-biotech Applications, www.isaaa.org; www.ams.usda.gov/rules-regulations/be; http://sitn.hms.harvard.edu/flash/2015/from-corgis-to-corn-a-brief-look-at-the-long-history-of-gmo-technology/; allianceforscience.cornell.edu/blog/2020/06/analysis-usdas-final-biotech-rule-explained; private interviews

BY Des Keller

PHOTOS: DES KELLER

DOLLARS MAKE THE DIFFERENCE

These growers divide acres between transgenic and nontransgenic crops to capitalize on the best markets.

Kevin Stoy is the office guy, the business manager and the marketer of the eastern Indiana farm he, his two brothers, Tom and Ken, and their father, Larry, have grown to nearly 18,000 acres from 1,300 nearly 30 years ago. Their business strategy has been for several years to focus on what they do best: grow nongenetically modified (GM) soybeans and GM corn—and be able to market the heck out of them.

The Stoys' decisions are all harnessed to the bottom line. The pragmatic approach has led them to plant all GM corn hybrids while planting 100% of their soybeans to non-GM varieties. They've grown non-GM soybeans for years, even when they weren't selling them for a premium.

Kevin Stoy

The bulk of their non-GM soybeans are contracted with two grain elevators that, in turn, aggregate large enough quantities to rail them to a crush facility. The meal is sold to poultry companies and the oil to other specific end users. Premiums run $1.25 to $1.50 per bushel.

"We tried non-GM corn and couldn't get it to pencil out like the non-GM beans," Stoy says. The availability of cost-effective multiple modes of action in soybean herbicides is crucial. So is the good yield capability and lower cost of non-GM soybean seed.

"We've grown beans for as high or higher yields than GMs with lower input costs," he continues. Herbicides that were once under patent—like Pursuit (Group 2 ALS herbicide)—could cost $17-plus per acre or more to apply, but can now be applied for $3.50 per acre.

NON-GM TRENDS

In 2020, there were about 13 million acres in the U.S. devoted to non-GM corn and soybeans—about 8% of all corn grown and roughly 6% of all soybeans, according to Mercaris, which collects market data and facilitates sales in the organic, non-GM and other IP (identity preserved) markets.

"Over nearly the past seven years, those levels have been fairly stable," says Ryan Koory, Mercaris director of economics. GMs in row crops were introduced in 1996 in the U.S., and their use grew quickly. The numbers would suggest the use of GM crops has plateaued within the U.S. The market for non-GM crops shows potential for more growth, Koory explains.

"The trends have shown consumers are concerned about other aspects of their food—the social, health and environmental impacts," he says. "I don't see those trends going away anytime soon."

Mercaris data shows the premium for feed-grade non-GM soybeans the past three years has averaged anywhere from 33 cents to $1.17 per bushel. During that same period, feed-grade non-GM soybeans have drawn premiums ranging from 48 cents to $1.86 per bushel. As for food-grade soybeans, premiums varied from $1.10 to $3.05 per bushel during the past three years.

About 8% of all corn acres in the U.S. were non-GMO in 2020. DES KELLER

BOTTOM LINE COUNTS

In Cotton Plant, Arkansas, Adam Chappell helped lead the family farm from the brink of financial ruin 10 years ago by moving to what is being referred to as "regenerative agriculture," the use of cover crops to help soil health, manage water and suppress weed production. Part of the equation for them was using significant amounts of non-GM seed, mostly because the seed cost was considerably less.

Chappell uses multiple non-GM public varieties. Including seed-cleaning costs, he reports spending roughly $14 per bag compared to $45 to $80 per bag for GM soybean varieties. He adds yields are comparable between the two varieties.

"My interest is purely about business," Chappell says. "I don't have a problem with GMs, and we still use them for about 30% of our crops." He, brother Seth and their father grow cotton, corn and soybeans, and run cattle on 8,000 acres.

"We can use public varieties on soybeans and save back seed," Chappell says. "It's huge cost savings on the front end and a premium on the back end." Their non-GM soybeans are sold to nearby poultry operations that market non-GM fed chickens. "The extra management I have to do with non-GM is worth it to me."

MSU AG COMMUNICATIONS

The non-GM soybeans are contracted to a regional poultry company. Premiums range from $1 to $2 per bushel depending on the year and delivery date.

Should the demand market or herbicide technology change, Chappell says he can certainly shift back. "If everybody goes back to GMs, and there's no more premium for non-GMs, that's fine with me—it's an easy transition back," he says. He doesn't see the market moving that direction, though. >

CHOICES FOR CONSUMERS

Of course, markets greatly dictate what farmers ultimately decide to grow.

"What we've learned from the introduction of GM crop technology is that the consumer wants to have an opinion," says Eric Wenberg, executive director of Specialty Soya and Grains Alliance (SSGA), a business trade group of seed companies, wholesalers and transportation firms that supply specialty and identity-preserved soybeans, corn and small grains in the U.S. and overseas. "If you're a food manufacturer, you do what the customer tells you to do."

Formed less than two years ago, SSGA makes sure the issues important to the specialty-crop industry "don't fall off the table," Wenberg says. Certainly, there is more demand for many specialty crops like non-GM soybeans.

"Our members need more food-grade soybeans, and they need more non-GM soybeans, but do they have the premium necessary to activate farmers to grow it?" Wenberg asks. "I think what they've proven is that they are willing to pay."

Profit is the name of the game for Stoy Farms. They grow GM corn but non-GM soybeans.
DES KELLER

The value of U.S. soybean exports is about $18 billion annually with non-GMs making up about 10% of the total. That slice of the pie is increasing, Wenberg believes. "I think that when we speak of where agriculture is headed, it is to provide a specified crop for specified customers. "If the past 25 years have taught us anything, it is that we can't market one thing—we have to market many things well."

Indiana's Stoy may not want to grow many things well at the same time.

Not too many years ago, the Stoys grew three types of soybeans: GMO, non-GMO and Plenish-brand high oleic oil soybeans. Keeping the three separated in terms of storage and equipment was just too much. Likewise, they used to sell crop insurance, run cattle and raise seed for Pioneer. They grew potatoes for two years and parsley for 15—crops that went into Campbell's soups. All of that is gone now.

"We've come full circle," Stoy explains as we walk in a field of non-GMO soybeans—part of the 8,000 acres they grew in 2020. "Sometimes, sidelines can hurt you. In our case, we decided that if we weren't going to be the best at certain things, we wouldn't do them."

For 2021, Stoy says they will likely reduce their non-GM soybean acres because of issues with dicamba moving off-target from neighbors' Xtend soybean fields.

That said, Stoy doesn't rule anything out in the future. "We're always worried about sustainability. We want to be able to compete with virtually any opportunity that comes up, which is really the ultimate sustainability." ///

BY Emily Unglesbee

BRAVE NEW PLANT WORLD

These GM crops may be the technology's best chance to win over the public.

GETTY IMAGES

Imagine breakfast without coffee. Or bananas. Or orange juice! All come to our table from crops facing pest problems serious enough to threaten their future—and the answer to their survival may depend on genetic tinkering.

Will consumers be more accepting of genetically modified (GM) food if they are faced with going without?

ISAGANI SERRANO, INTERNATIONAL RICE RESEARCH INSTITUTE

Read on to find a sampling of some GM plants and foods that have made it through punishing regulatory paths and are poised to change parts of the world—and maybe even the minds of wary consumers.

Golden Rice (bottom left) has been engineered to deliver extra Vitamin A, with the goal of preventing blindness in millions of people worldwide.

RICE WITH A VIEW

The World Health Organization estimates that vitamin A deficiency affects millions of children and pregnant women worldwide each year, and is the leading cause of preventable childhood blindness. For years, vitamin supplementation programs have been put in place by global relief groups to try to end this suffering.

Then in 1999, scientists made a breakthrough: They genetically engineered a strain of rice to produce high levels of beta-carotene, which our bodies convert to vitamin A. Five years later, another strain of rice was developed, which produced even more beta-carotene. Known as Golden Rice, these yellow-colored grains of rice have been hailed as a lifesaving discovery and even netted a Patents for Humanity award in 2015.

Anti-GM protests, regulatory hurdles and the plodding pace of rice breeding have slowed the rice's progress. In recent years, however, Golden Rice gained regulatory approvals for consumption in Australia, Canada, New Zealand, the Philippines and the U.S. As of press time, at least two countries, Bangladesh and the Philippines, were also considering issuing regulatory approvals to plant and grow Golden Rice varieties.

RESURRECTING AN AMERICAN CLASSIC

Once a proud pillar of North American forests, the American chestnut tree has become a critically endangered species, brought to the brink of extinction by an invasive fungal disease called chestnut blight. First found in the U.S. in 1904, the blight has wiped out billions of chestnut trees, once prized for their edible nuts and fast-growing, high-quality hardwood.

The American chestnut tree has been the target of multiple scientific rescue missions, including attempts to backcross remaining trees with the Chinese chestnut, which is resistant to the blight. Some of the most promising efforts to resurrect the original, however, involve biotechnology.

American Chestnut

Efforts to save the American chestnut tree include several GM versions, including timber-quality trees such as this one in a Pennsylvania orchard. EMILY UNGLESBEE

Researchers at SUNY New York's College of Environmental Science and Forestry have developed a GM chestnut variety that expresses a wheat gene that allows it to survive blight infections.

The GM American chestnut variety is currently awaiting USDA's decision on its deregulation, which would allow it to be released in U.S. forests. ///

A PAPAYA WITH A PURPOSE

Just two decades ago, the papaya—the popular golden-colored tropical fruit packed full of Vitamin C and flavor—was in trouble. A stubborn disease called the Papaya ringspot virus was plaguing growers around the world and threatening future production.

Scientists from Cornell University and the University of Hawaii rapidly developed one of the world's first GM (genetically modified) fruits, a papaya genetically engineered to resist the ringspot virus. These public-sector scientists were able to distribute the first resistant seeds to Hawaiian farmers in 1998. By 2009, the Rainbow papaya, as it is known, accounted for 77% of the islands' papaya production.

Like many GM crops, the Rainbow papaya has been the target of anti-GM activists, who have stalled efforts to develop additional GM ringspot-virus-resistant papayas in other countries, such as Taiwan and Thailand. But, some of the world is slowly coming around: Canada has been importing the GM papaya since 2003, and Japan since 2012.

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STORY AND PHOTOS BY *Des Keller*

BACK TO THE **FUTURE**

When holes began to appear in genetically engineered technology designed to control weeds and pests, these growers returned to time-proven practices of previous generations.

Lewis Stearns is having to learn more about weed control and chemistries because of weed resistance.

The year 2019 was an eye-opener for Bloomdale, Ohio's, Lewis Stearns, the founder of the consulting company Progressive Crop Solutions. European corn borers were taking a serious toll on the corn fields of several clients.

"I wasn't super accustomed to seeing these insects, because Bt corn has been part of the market as long as I've been around," says Stearns, who is 29 and has never known anything other than genetically modified (GM) crops. In fact, the first commercial GM crops introduced 25 years ago incorporated the bacterium bacillus thuringiensis (Bt) specifically to fight pests like European corn borers.

Stearns is part of a generation of farmers that has grown up with GM technology, which now is engineered into most primary row crops with multiple modes of action against pests and weeds. However, documented cases of resistant insect and weed populations are on the rise because of overreliance on certain traits and not diversifying management practices.

DÉJÀ VU

That's causing Stearns' generation to pivot and think back to control measures their fathers used as resistant pests and weeds make life more complicated even with transgenic crops.

"We're kind of back to where we were 30 years ago," says Bill Johnson, longtime weed scientist at Purdue University. "Our weed control and tank mixes had gotten very complex by the early '90s. We had three- and four-way mixtures and adjuvants to try and beat things back like waterhemp and cocklebur. We'd gotten really good at understanding tank mixes and adjuvants."

Not that anyone needs or wants to return to that era, but farmers did lose some understanding of weeds and their control, Johnson says. Some of that knowledge is now having to be relearned.

Transgenic traits that endowed crops to remain unharmed from herbicides such as glyphosate allowed producers to lose their appreciation that smaller weeds are easier to kill, Johnson explains. The utilization and setup of a sprayer, along with incorporating preplant herbicides and between-row cultivation is "kind of a lost art."

Stearns believes GM crops have saved farmers on pesticide costs and time spent spraying while using a herbicide (glyphosate) that he contends poses fewer health risks than the alternatives. As time goes on, Stearns also is having to learn more about weed control and chemistries with multiple modes of action because of weed resistance. ➤

Herbicide-tolerant traits ushered in a new era of controlling weeds to protect yield.

"Initially in our area, marestail was a big issue," Stearns says. "Now, there is fall spraying with either 2,4-D or dicamba, and now you hardly hear about it." The focus then shifted to waterhemp in an effort to keep it from germinating in the first place. "Once it is growing, it's really hard to stop," he says. "You can't kill it much over 4 inches tall."

The ease of farming using genetically modified glyphosate-tolerant crops "pretty much destroyed the herbicide-development industry," says David Franzen, Extension soil specialist at North Dakota State University. "Why would a company spend tens of millions of dollars to bring a new product to registration and have to compete against something [glyphosate-resistant crops] with 98% of the market?

"Even if they start development of new technology today with new modes of action, it will take years to bring something to market that will be different," Franzen explains. Crops tolerant to glyphosate and other herbicides have helped create "weeds stronger than anything we've ever seen before. We're back to the future, but now the spectrum is different, and the number of herbicide groups to which there are resistant weeds is greater."

GREATER EFFICIENCIES

Would the industry, or farmers for that matter, trade the relatively simplified version of farming the past 20-plus years if they knew where we would be now?

Maybe. Maybe not. Derek Nelson, 38, began farming with in-laws on 4,000 acres near Manson, Iowa, in 2014. The operation is 100% corn after corn using 100% GM seed. A nonfarm kid from Minnesota, Nelson grew up believing farmers got up at 5 a.m. every day and worked till 10 p.m.

"This year, we sprayed everything with herbicide, all 4,000 acres, in eight days," he says. "It was a long eight days, but what would it have been without GM crops? Even more days? Weeks? Months?"

Though there are issues in the region with resistant weeds, Nelson hasn't seen many similar problems. "Once the corn gets up, weeds generally aren't an issue. We really haven't had to change much to adapt."

Nelson's 2020 weed-control program included Balance Flexx and Atrazine 4L applied preemerge with nitrogen and cultivated in. In early June, acres were treated postemerge with Class Act, Laudis and Roundup PowerMax.

"I think of the time saved that I can be with my family," Nelson says. He and wife, Jill, have four young children. "Would we even have a 32-row planter if there was no GM corn?"

Probably not, Purdue's Johnson and North Dakota State's Franzen agree. The ease of operation that GM crops ushered in allowed farms to grow, which pushed machinery to become larger.

"Do you really think someone would be able to farm 40,000 acres with the herbicide systems of 25 years ago?" Franzen asks.

Kari Olson, 24, farms with her father near Hawley, Minnesota, on less than 3,000 acres growing corn, soybeans and wheat. She's thankful for the GM seed ➤

options she's grown up with, especially because the operation is 100% no-till.

"This modern technology has allowed us to maximize our yields on less acres and resources while reducing crop loss, pesticide and fertilizer use," Olson says. She concedes that weed resistance has started to become an issue in the region.

"We need different modes of action from chemicals."

–*Lewis Stearns*

Currently, there is no GM wheat grown in the U.S.; so, by definition, all wheat is non-GM. Olson isn't certain they would use GM wheat were it available.

"I am hesitant to have another variety tolerant to glyphosate," she says. "My reasoning being, we need different modes of action from chemicals in a crop rotation to prevent the increase in glyphosate-resistant weeds."

WARNING SIGNS

Both Franzen and Johnson saw the weed-resistance issues coming as a result of what they say was the wildly popular overuse of GM crops and partnered herbicides.

Stearns keeps a close watch for waterhemp because the weed is difficult to control.

In 1991, Franzen studied at the University of Illinois the possibility of plants becoming resistant to certain herbicides. "It wasn't hard to work out the scenario," he says. "There are millions upon millions of seeds per acre in these weeds. Did we think they wouldn't somehow segregate into those that can survive a particular mode of action versus those that won't? That's how selective breeding works."

What might have been different?

"I would have limited the amount of glyphosate and Roundup Ready soybean that each user could purchase so they had to be better stewards of the product," Johnson says. "Also, bundling glyphosate with other herbicides would have forced growers to have more diverse weed-control programs, as well." He believes such measures would have forestalled resistance issues for at least another decade.

Franzen says the new generation of farmers has to learn what their fathers and grandfathers had to learn: "weed and insect identification, integrated pest-management strategies, herbicide phytotoxicity potential to crops and crop-rotation restrictions from the use of some pesticides." ///