How To Genetically Modify a Seed, Step By Step

FEATURE

Using nature as a guide, geneticists build plants with qualities evolution could never produce
By Rebecca Boyle Posted 01.24.2011 at 2:59 pm 10 Comments

Soybeans in Automated Greenhouse Genetically modified soybean plants grow at Monsanto's automated greenhouse in Raleigh, N.C. The greenhouse has conveyor belts to move plants around for watering, weighing, and pictures, so scientists can monitor their health without ever having to handle them. Courtesy Monsanto
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ST. LOUIS — In a nondescript basement lab, jeans-clad engineers clutch blueprints, scrape stepladders across the unfinished floor and chat about the Cardinals as they tighten bolts on a new prototype device. At first glance, it could be any machine shop in the country.

But then you notice the wispy strands of soybean seedlings curling to life, their root tendrils bunched into test tubes lightly packed with soil, and you remember — this place is all about seeds.

Monsanto Co. produces 90 percent of the world's transgenic crops, using a complex marriage between ancient techniques — cross-breeding different plants to produce a desired trait — and the most modern technologies available, from genomic research to NASA-caliber mechanical engineering.

Originally a chemical company, Monsanto produced some of the world's most controversial substances — saccharine, DDT, PCBs, Agent Orange — before evolving into the biotech giant it is today. That evolution has been marked by controversy, including lawsuits against farmers, allegations of unfair trade practices, and more. The company produces the herbicide Roundup, and also seeds whose genes have been engineered to survive Roundup's active plant-killing ingredient. Now the vast majority of this country's soybeans, corn, sugar beets and canola possess those engineered genes.

For a closer look at the tools of the GE trade, check out the gallery here

Behind every single seed is at least a decade of research involving geneticists, engineers and farmers, working to produce a seed that will grow exactly as expected, and in a way nature may not have intended. Here's how it's done.

Step one: Finding a new trait

Ginny Ursin, head of technology prospecting at Monsanto, has been studying plants most of her life; at age 10, she cobbled together a makeshift greenhouse in the front yard. It was well-built enough that a city building inspector dropped by to inquire about a permit, she recalled. After obtaining her Ph.D in genetics from the University of California-Davis, she studied the biochemical pathways that allow plants to accumulate oil. She has spent more than a decade developing a new omega-3 soybean, which actually produces a precursor fatty acid that our bodies convert into a heart-healthy type of omega-3 — fish oil without the fish. Its history includes Alaskan wildflowers, a type of mold used in Indonesian cooking and years of patient cultivation.

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To produce a genetically modified organism, you have to identify the trait you want the plant to have, and find out what other organisms already have it. This involves luck as much as careful searching — Monsanto first produced "Roundup Ready" glyphosate-tolerant plants using a gene from bacteria found growing near a Roundup factory. Ursin pored over science texts outlining organisms' fatty acid compositions, tested hundreds of flowers and fungi, and finally narrowed down the web of life to two fatty-acid-producing enzymes found in primrose flower and a mold called neurospora.

Concocting a transgenic soybean seed also involves testing the plants themselves to find the most worthy subjects. Monsanto invented some cutting-edge technology to help its scientists make that step more efficient.

Step two: Grabbing genes

In the past, studying the genetic code of individual seeds required planting the seed, growing the plants to a certain size, and then clipping a paper-hole-puncher through a leaf to gather a sample. But that's a time-consuming and resource-heavy process, so it's easier to study the seeds themselves, explains Kevin Deppermann, head of Monsanto's automation engineering department. This requires grinding them up, which is also inconvenient, because a ground-up seed can't be planted. To get around this, Monsanto engineers invented a special chipping device that shaves off just a tiny piece of the seed and grinds it into a powder that can be analyzed with genome-mapping technology. Meanwhile, the viable remainder of the seed is preserved for planting and cultivation.

"Now we know what genes are in the seed before it's in the ground," Deppermann said.

Chipped Soybeans: Courtesy Monsanto

Deppermann boasts that he recently hired away an engineer from NASA's Jet Propulsion Laboratory and that he believes with the right tools, Monsanto will be able to meet its goal of tripling crop yields while reducing resource use by two-thirds by 2030. He says the chipper, which Monsanto patented last year, is one such tool. A blast of air separates the shavings from the rest of the seed; a bar code system ensures the two can be reconciled later. The device, about the size of a home air conditioner, can chip a seed every second. The chip is ground to a fine powder and analyzed with an automated high-throughput genotyping system, also developed in-house.

It was easy to design a chipper for soybeans, because the seeds are shaped such that they always fall a certain way. But corn kernels are all different, and you don't want to shave off the wrong part and kill the embryo. Monsanto's corn chipper uses cameras and object-recognition algorithms to determine how each seed should be aligned for proper chipping. Next-generation chippers for melons and other fruits have a camera that takes 100,000 frames per second — all to help geneticists find new traits even faster.

Step three: "Trait insertion"

Now that you've got your genes, the next step is inserting them into the plants. There are a couple ways to do this, including using "gene guns" that literally shoot pieces of DNA. A .22-caliber charge fires a metal particle coated with DNA into plant tissue. Monsanto no longer uses the technique, but it's still widely used among other biotech companies.

For omega-3 soybeans, Ursin and colleagues used a slightly more delicate process, heating soybean seedlings to place them under stress and make them susceptible to a bug called *Agrobacterium tumefaciens*. The organism specializes in invading plant DNA and tricking it into producing sugars and amino acids that feed the bacteria. Scientists can exploit this Trojan horse ability and insert new proteins into the plant's chromosomes. The plant recognizes this foreign encoded protein as one of its own, Ursin said.

"This is now in all the plant progenitor cells. The pollen will have that DNA in its genome, so when you have a pollination event and create new seed, that trait is advanced into the next generation," she said. And there you have it: a first-generation genetically modified plant.

It's also a game of chance — just like with breeding, you never know how the offspring will turn out. Ursin and colleagues produced large sets of modified seedlings to make sure the new genes ended up in the right spot on the genome, because if they don't, the plant could suffer myriad side effects that would make it unsuitable for sale (at a premium price) to farmers. The next step: finding the best candidates.

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Link to this comment
racinjetford
01/24/11 at 9:49 pm

This is so cool! I'm inspired. I've been doing tillage work with farmers for a year, and I've just started school to get a science degree. I think I want to be involved in the next push for better crops and better yields! We are learning about the Agricultural Revolution right now in my History class. Better farming (through science and technology) has allowed the rest of us to do things other than farming (to feed ourselves). This has freed labor and brainpower to do other things. Where would the modern world be without the crop yields of today? We'd all be so busy growing food that nobody would have the time or resources to study, invent, produce, or consume anything else! Productivity and wealth would decrease drastically.
Now we just need scientists out there to find a way to power big tractors when fossil fuels aren't so abundant! We would be in a world of hurt without the tractor... The old world, that is.

Link to this comment
MagLabKat
01/25/11 at 5:33 pm

Very informative, well-written story. While I am not a fan of genetically modified food - i.e., I try to avoid knowingly buying it, although I'm sure all the fresh corn I buy is GM - I want to learn more about the issue. Thanks for doing this story!

Link to this comment
tertertert
01/26/11 at 12:47 am

You forgot steps 7 and 8.