

THE FUTURE OF FOOD

Super Organics

Forget Frankenfruit - the new-and-improved taste of tomorrow is Earth-friendly and all-natural. Welcome to the delicious golden age of gene science.

by Richard Manning illustration by Alexis Rockman

Once upon a technologically optimistic time, the founders of a swaggering biotech startup called Calgene bet the farm on a tomato. It wasn't just any old tomato. It was the Flavr Savr, a genetically engineered fruit designed to solve a problem of modernity.

Back when we all lived in villages, getting fresh, flavorful tomatoes was simple. Local farmers would deliver them, bright red and bursting with flavor, to nearby markets. Then cities and suburbs pushed out the farmers, and we began demanding our favorite produce year-round. Many of our tomatoes today are grown in another hemisphere, picked green, and only turn red en route to the local Safeway. Harvesting tomatoes this way, before they've received their full dose of nutrients from the vine, can make for some pretty bland fare. But how else could they endure the long trip without spoiling?

Flavr Savr was meant to be an alternative, a tomato that would ripen on the vine and remain firm in transit. Calgene scientists inserted into the fruit's genome a gene that retarded the tendency to spoil. The gene-jiggering worked - at least in terms of longer shelf life,

Then came the backlash. Critics of genetically modified food dubbed the Flavr Savr "Frankenfood" Sparked by the Flavr Savr's appearance before the US Food and Drug Administration, biotech watchdog Jeremy Rifkin set up the Pure Food Campaign, stalling FDA approval for three years and raising a ruckus that spread to Europe. When the tomato finally emerged, it demonstrated that there was no accounting for taste at Calgene. Flavr Savr wasn't just oddly spelled; it was a misnomer. Even worse, the fruit was a bust in the fields. It was highly susceptible to disease and provided low yields. Calgene spent more than \$200 million to make a better tomato, only to find

In some cases, GMOs have fulfilled their promise. They've allowed US farmers to be more productive without as much topical pesticide and fertilizer. Our grocery stores are stuffed with cheaply produced food - up to 70 percent of all packaged goods contain GM ingredients, mainly corn and soybean. GM has worked even better with inedible crops. Take cotton. Bugs love it, which is why Southern folk music is full of tunes about the boll weevil. This means huge doses of pesticides. The world's largest cotton producer, China, used to track the human body count during spraying season. Then in 1996, Monsanto introduced BT cotton - a GMO that employs a gene from the bacterium *Bacillus thuringiensis* to make a powerful pesticide in the plant. BT cotton cuts pesticide spraying in half; the farmers survive.

But while producers have embraced GMOs, consumers have had a tougher time understanding the benefits. Environmentalists and foodies decry GMOs as unnatural creations bound to destroy traditional plants and harm our bodies. Europe has all but outlawed transgenic crops, prompting a global trade war that's costing US farmers billions in lost exports. In March, voters in Mendocino County, California, banned GMO farming within county lines,

Opponents have found an ally in crop scientists who condemn the conglomerates behind transgenics, especially Monsanto. The company owns scores of patents covering its GM seeds and the entire development process that creates them. This gives Monsanto a virtual monopoly on GM seeds for mainline crops and stifles outside innovation. No one can gene-jockey without a tithe to the life sciences giant.

Which brings us back to smart breeding. Researchers are beginning to understand plants so precisely that they no longer need

Farmers used to crossbreed year after year. Now gene jocks can unlock traits on the fly.

itself awash in red ink. Eventually, it was swallowed by Monsanto.

But the quest for a longer-lasting tomato didn't end there. As the Flavr Savr was stumbling (Monsanto eventually abandoned it), Israeli scientist Nachum Kedar was quietly bringing a natural version to market. By crossbreeding beefsteak tomatoes, Kedar had arrived at a savory, high-yield fruit that would ripen on the vine and remain firm in transit. He found a marketing partner, which licensed the tomato and flooded the US market without any PR problems. The vine-ripened hybrid, now grown and sold worldwide under several brand names, owes its existence to Kedar's knowledge of the tomato genome. He didn't use genetic engineering. His fruit emerged from a process that's both more sophisticated and far less controversial.

Welcome to the world of smart breeding.

The tale of the Flavr Savr is a near-perfect illustration of the plight of genetically modified organisms. A decade ago, GMOs were hailed as technological miracles that would save farmers money, lower food prices, and reduce the environmental damage unintentionally caused by the Green Revolution - a movement that increased yields but fostered reliance on chemical fertilizers, pesticides, and wanton irrigation. Gene jocks said they could give us even greater abundance and curb environmental damage by inserting a snip or two of DNA from another species into the genomes of various crops, a process known as transgenics.

transgenics to achieve traits like drought resistance, durability, or increased nutritional value. Over the past decade, scientists have discovered that our crops are chock-full of dormant characteristics. Rather than inserting, say, a bacteria gene to ward off pests, it's often possible to simply turn on a plant's innate ability.

The result: Smart breeding holds the promise of remaking agriculture through methods that are largely uncontroversial and unpatentable. Think about the crossbreeding and hybridisation that farmers have been doing for hundreds of years, relying on instinct, trial and error, and luck to bring us things like tangelos, giant pumpkins, and burpless cucumbers. Now replace those fuzzy factors with precise information about the role each gene plays in a plant's makeup. Today, scientists can tease out desired traits on the fly - something that used to take a decade or more to accomplish.

Even better, they can develop plants that were never thought possible without the help of transgenics. Look closely at the edge of food science and you'll see the beginnings of fruits and vegetables that are both natural and supernatural. Call them Superorganics - nutritious, delicious, safe, abundant crops that require less pesticide, fertilizer, and irrigation - a new generation of food that will please the consumer, the producer, the activist, and the FDA.

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Nearly every crop in the world has a corresponding gene bank consisting of the seeds of thousands of wild and domesticated relatives. Until recently, gene banks were like libraries with millions of dusty books but no card catalogs. Advances in genomics and information technology - from processing power to databases and storage - have given crop scientists the ability to not only create card catalogs detailing the myriad traits expressed in individual varieties, but the techniques to turn them on universally.

One of the smart breeder's most valuable tools is the DNA marker. It's a tag that sticks to a particular region of a chromosome, allowing researchers to zero-in on the genes responsible for a given trait - a muted orange hue or the ability to withstand sea spray. With markers, much of the early-stage breeding can be done in a lab, saving the time and money required to grow several generations in a field. Once breeders have marked a trait, they use traditional breeding tactics like tissue culturing - growing a snip of plant in a nutrient-rich medium until it's strong enough to survive on its own. One form of culturing, embryo rescue, allows breeders to cross distant relatives that wouldn't normally produce a viable offspring. This is important because rare, wild varieties often demonstrate highly desirable characteristics. After fertilization, a breeder extracts the premature embryo and fosters it in the lab. Another technique - anther culture - enables breeders to develop a complete plant from a single male cell,

The science behind some of these techniques makes transgenics look unsophisticated. But the sell is simple: Smart breeding is the best of transgenics crossed with the best of organics. It can feed the world, heal the earth, and put an end to the Big Ag monopoly.

Take it from Robert Goodman, the former head scientist at Calgene who now works with the McKnight Foundation, overseeing a \$50 million program that funds genomics research in the developing world. "The public argument about genetically modified organisms, I think, will soon be a thing of the past," he says. "The science has moved on."

In the mid-'80s, a grad student in plant breeding at Cornell University was handed a task that none of her peers would take. Her name: Susan McCouch. Her loser assignment: Create a map of the 40,000 genes spread across the rice genome. In 1988, the completion of that work would be heralded as a scientific breakthrough. Sixteen years later, it's beginning to shake corporate control of science.

A genome map is a detailed outline of an organism's underlying structure. Until McCouch came along, rice - the most important food for most of the world's poor - was an orphan crop for research. Big Ag was interested only in the Western staples, wheat and corn. But good maps enlighten - geologists once looked at maps of South America and Africa and figured out that the edges of the two continents fit together, giving rise to the idea of plate tectonics. McCouch's map was just as revealing. Researchers compared it to the genomes of wheat and corn and realized that all three crops, along with other cereal grasses - more than two-thirds of humanity's food - have remarkably similar makeups. The volumes of research into corn and wheat could suddenly be used to better understand developing world essentials like rice, teff, millet, and sorghum. If scientists could find a gene in one, they'd be able to locate it in the others.

By extension, characteristics of one crop should be present in related plants. If a certain variety of wheat is naturally adept at defeating a certain pest, then rice should be, too; scientists would just need to switch on that ability. McCouch started her project as a way to

How Smart Breeding Works

The mission: Develop rice that's resistant to bacterial blight and will thrive around the globe.

1 SEARCH Food scientists scour the rice **gene bank**, consisting of 84,000 seed types, in search of varieties with blight immunity.



2 INSERT MARKER Scientists extract DNA from selected varieties and tag the blight-immunity gene - previously identified by researchers - with a chemical dye.

3 CROSSBREED A network of researchers around the world cross disease-resistant varieties with thousands of local versions. With some plants, this means merely putting two varieties in a room. Self-pollinating rice requires manual pollen insertion.



4 ANALYZE The offspring are analyzed to detect the presence of the immunity gene. Those containing the gene are **planted in a field**.

5 TEST Mature plants are exposed to bacterial blight to confirm resistance. Those that don't die, and maintain desired traits from the local variety, are distributed. Unless...



6 REPEAT Sometimes, the process reveals several genes responsible for a trait. Three genes confer resistance to different blight strains. In such cases, breeders repeat the crossbreeding until all genes are turned on.

7 END RESULT A rice plant with broad resistance to bacterial blight that will thrive in local conditions.

unlock the door to the rice library; it turned out she cut a master key.

Still at Cornell, McCouch is now learning how crossbreeding domesticated, rice with wild ancestors can achieve super-abilities that neither parent possesses. "We're finding things like genes in low-yielding wild ancestors, which if you more them into cultivated varieties can increase the yields of the best cultivar," McCouch says. "Or genes of tomatoes that come out of a wild background - they make a red fruit redder. We also have ways to make larger seeds, which can yield bigger fruit." Generations of unscientific plant breeding have inadvertently eliminated countless valuable genes and weakened the natural defenses of our crops. McCouch is recovering the complexity and magic

Food scientists around the world are picking up on her work. In China, researcher Deng Qiyun, inspired by McCouch's papers, used molecular markers while crossbreeding a wild relative of rice with his country's best hybrid to achieve a 30 percent jump in yield - an increase well beyond anything gained during the Green Revolution. Who will feed China? Deng will. In India, the poorest of the poor can't afford irrigated land, so they grow unproductive varieties of dryland rice. By some estimates, Indian rice production must double by 2025 to meet the needs of an exploding population. One researcher in Bangalore is showing the way. H. E. Shashidhar has cataloged the genes of the dryland varieties and used DNA markers to guide the breeding toward a high-yield super-rice. In West Africa, smart breeders have created Nerica, a bountiful rice that combines the best traits of Asian and African parents, Nerica spreads profusely in early stages to smother weeds. Its disease-resistant, drought-tolerant.

Monsanto & Co. are losing their monopoly - it's agriculture's version of open source.

and contains up to 31 percent more protein than either parent.

This is not exclusively a matter of crafting new rice varieties in the developing world. Irwin Goldman, a horticulture professor at University of Wisconsin-Madison, cites McCouch's work as critical to the progress he's made with carrots, onions, and beets. For example, he has spawned a striped beet through some sophisticated genome tweaking - and in the process revealed methods to improve the appearance and taste of all sorts of vegetables.

Beet genes make two pigments of a class of chemicals called betalain. When both are present, the beet is red. Switch off one gene, as happens in natural mutations, and the beet is gold. Switch it on and off at different stages and the beet becomes striped. Creating a striped beet is not hugely important by itself - striped heirloom varieties date back to 19th-century Italy. What's significant is that Goldman pinpointed the genes responsible for the trait and figured out how to turn them on.

This type of smart breeding may one day lead to something as useful as a high-yield rice that's naturally rich in beta-carotene, which our bodies convert to vitamin A. For years, genetic engineers have been trying to introduce so-called golden rice to Asia, where vitamin A deficiency causes millions of people to go blind every year. Creating the GM version wasn't easy - it required the insertion of two daffodil genes - but it wasn't nearly as difficult as getting it to the people. As with the Flavr Savr, golden rice drew the ire of the

Frankenfood crowd while running afoul of some 70 patents. A natural counterpart wouldn't encounter such problems. Far-fetched? Maybe, considering that there's no known naturally occurring rice containing beta-carotene. Then again, we never thought carrots had vitamin E - until Goldman found some.

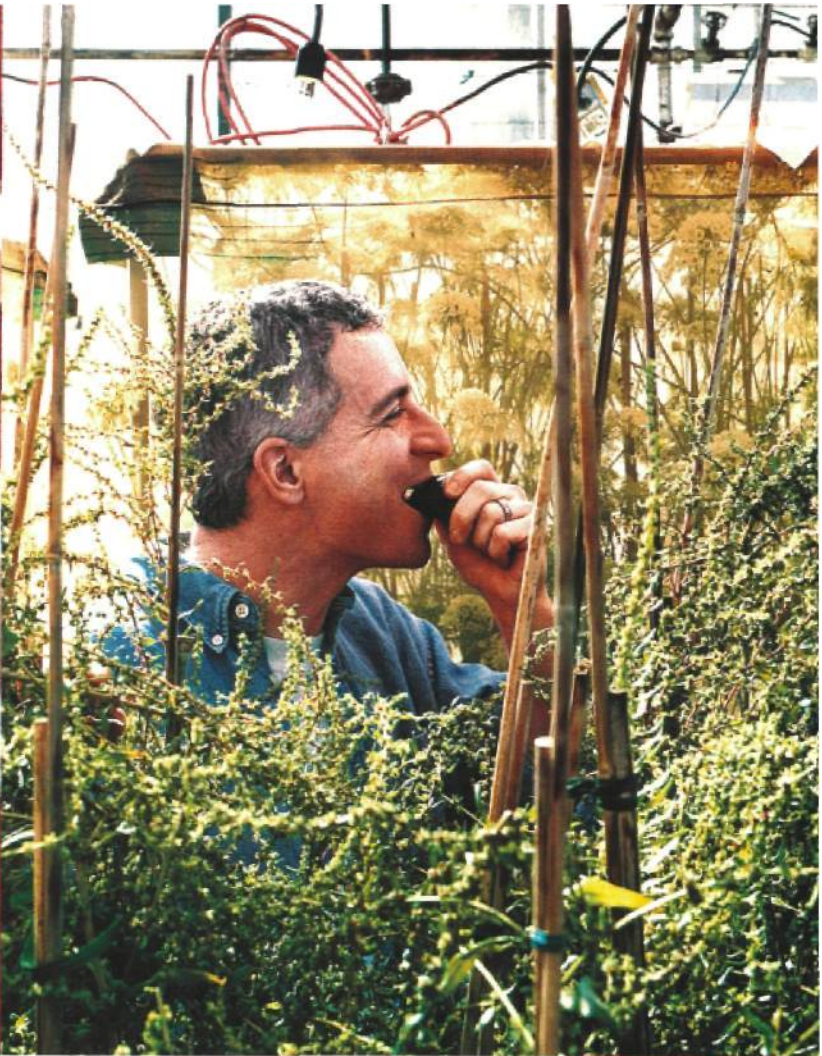
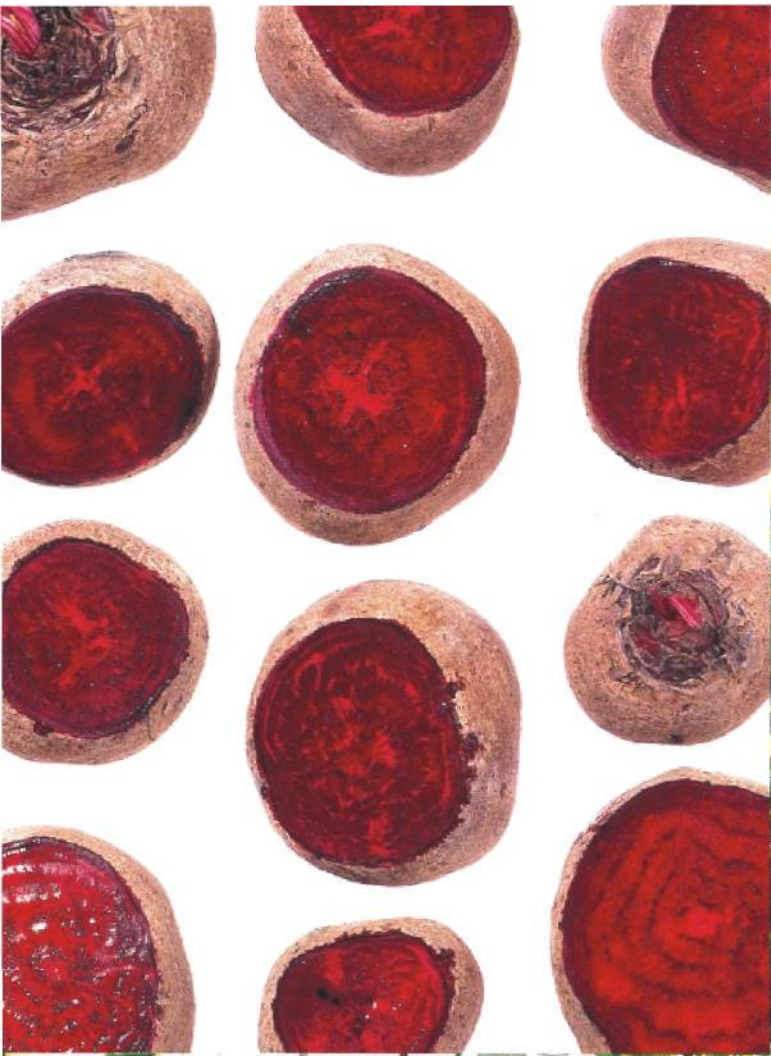
By scouring the carrot gene bank, Goldman discovered several exotic varieties of carrots (ranging in color from yellow to orange, red, and purple) that make vitamin E. Capitalizing on that native ability is a matter of tagging the relevant genes and crossbreeding the wild relatives with ordinary, everyday carrots. Gene bank searches are also revealing a whole host of antioxidants, sulfur compounds, and tannins - chemicals that bring sharp color and strong tastes - that have been stripped out of our lowest-common-denominator crops over the centuries. Many of these qualities not only fight cancer and increase the nutritional value of our vegetables, but also make them taste better while helping plants fight disease. We now have the ability to bring these traits back.

And we can do it quickly. It often takes seed companies several years to establish a new variety. To recover their investment, they release seeds that don't usually pass on the parents' traits, forcing farmers to buy new seed every year. Smart breeding, by contrast, is faster and cheaper because much of it can be done in the lab - reducing the time and expense of growing countless varieties in the field. Goldman's work is funded by university dollars, which allows him to give away the spoils. He links up with local organics growers, farmers' markets, and the expanding counter-agribusiness food movement and hands out open-pollinated seeds - ag's version of open source.

Richard Jefferson is an iconoclastic American bluegrass musician living in Australia. He's also a brash biotechnologist intent on wresting control of our crops away from Big Agriculture. As head of Cambia (the Center for the Application of Molecular Biology to International Agriculture), a plant science think tank in Canberra, he's sowing the seeds of a revolt, citing the open source ethos of Linus Torvalds and Richard Stallman as inspiration. "In the case of almost every single enabling technology, the corporations have acquired it from the public sector," he says. "They have the morals of stoats "

If McCouch and Goldman are making an end run around GMO by improving on methods that predate genetic engineering, Jefferson is taking a direct approach. All three scientists use an expanded knowledge of plant genomes to create new crop varieties. But where McCouch and Goldman do gene bank searches and study genome maps to figure out which plants to bring together, Jefferson digs into the genome itself and moves things around. He doesn't insert anything - he calls transgenics "hammer and tong science; as dull as dishwater" - but he's not above tinkering. His big idea: manipulate plants to teach ourselves more about them,

Jefferson made a name for himself as a grad student in 1986 when he discovered GUS, a clever little reporter gene that causes a glow when it's linked to any active gene. He distributed GUS to thousands of university and nonprofit labs at no cost - but charged the Monsantos of the world millions. He used the money to



Horticulturalist Irwin Goldman (above) eats an enhanced beet at the University of Wisconsin; Cambia's Richard Jefferson (left), amid stalks at UC Berkeley, aims to create biosentinel corn, a plant that would turn red when parched.



superorganics

establish Cambia, which invents technologies to help developing world scientists create food varieties without violating GMO patents,

Transgenic researchers treat the genome like software, as if it contained binary code. If they want an organism to express a trait, they insert a gene. But the genome is more complicated than software. While software code has two possible values in each position (1 and 0) DNA has four (A,C,T and G). What's more, a genome is constantly interacting with itself in ways that suggest what complexity theorists call emergent behavior. An organism's traits are often less a reaction to one gene and more a result of the relationship between many. This makes the expression of DNA fairly mysterious

Jefferson is out to master this squishy science with a practice he calls transgenomics. You are different from your siblings because your parents' genes were unzipped during reproduction and the 23 chromosomes on each half rejoined in a unique pattern. The same thing happens in plants. Jefferson has modified native genes to act as universal switches that turn a plant's latent genes on and off. Simply put, he's rigging the reproductive shuffle.

In a process he calls HARTs - homologous allelic recombination techniques - Jefferson manipulates genomes (no insertions allowed) to force plants to mimic other crops. "We're taking inspiration from one plant and asking another plant to make that change in itself," he says. One example Jefferson likes to talk about is sentinel corn - a plant-sized version of the GUS gene that would turn, red when it needs water. It may not sound like much, but by the time a traditional corn plant wilts, it's usually too late. More efficient irrigation would mean the difference between profit and loss - or nourishment and starvation.

Jefferson's greatest hope to challenge Big Ag comes in what's known as apomixis - plant cloning. He wants to teach all sorts of crops to clone themselves the way dandelions and blackberries do naturally. When a plant's seeds produce genetically identical offspring, there's no need to buy hybrid seeds every year. Jefferson and rival scientists claim to have several paths to apomixis - but the race is competitive and no one's offering details. The real problem, says Jefferson, is not developing the methods, but releasing them

into a world of patents. "I am not a technological optimist who thinks that if you put a technology out there, everything is going to be fine," he says. "How you put it out there matters as much or more than what it is."

His solution is to create an open source movement for biotechnology. In his vision, charitable foundations, which have paid for most of the world's public-interest crop science, would fund platform technologies and provide free licenses to public and private scientists. Commercial end products would be encouraged, but the basic technology, the OS, would remain in public hands. To get the whole thing started, Jefferson is offering up Cambia's portfolio of patents.

It's tempting to reach for the linux versus Microsoft analogy to describe Cambia's plan to unlock some of the astounding technologies that remain dormant in labs and greenhouses. It's powerful, but also decentralised, networked, and accessible - democratic. It's like Monsanto's mainframe giving way to biotech's equivalent of the PC.

Agriculture is one of the most ill-conceived human endeavors. We plow down stable communities of hundreds of species of plants to get single-row crops. We replace entire ecosystems with pesticides, fertilizers, precious fresh water, and tractor emissions. Then, after every harvest, we start all over again. Organic agriculture breaks this cycle. But it's just a Band-Aid on the wound.

Add the knowledge and tools of biotechnology, though, and we are on the verge of something enormous. Plant genomes carry age-old records that reveal the complex manner by which nature manages itself. Researchers around the world - McCouch, Goldman, and Jefferson are a few examples - are learning to not only read those records but re-create them.

Which is not to say success is automatic. This new era of food won't arrive with a technological big bang. But that's a good thing. Single events are too easy to control and monopolize. A steady trickle of innovation will buy time to get the marketing right. Public perception is as complex as the genome, and just as important to master. The science is taking hold. If the business side can clearly communicate what superorganics are - and what they are not - these new foods will not only change the way we eat, they'll change the way we relate to the planet. • • •