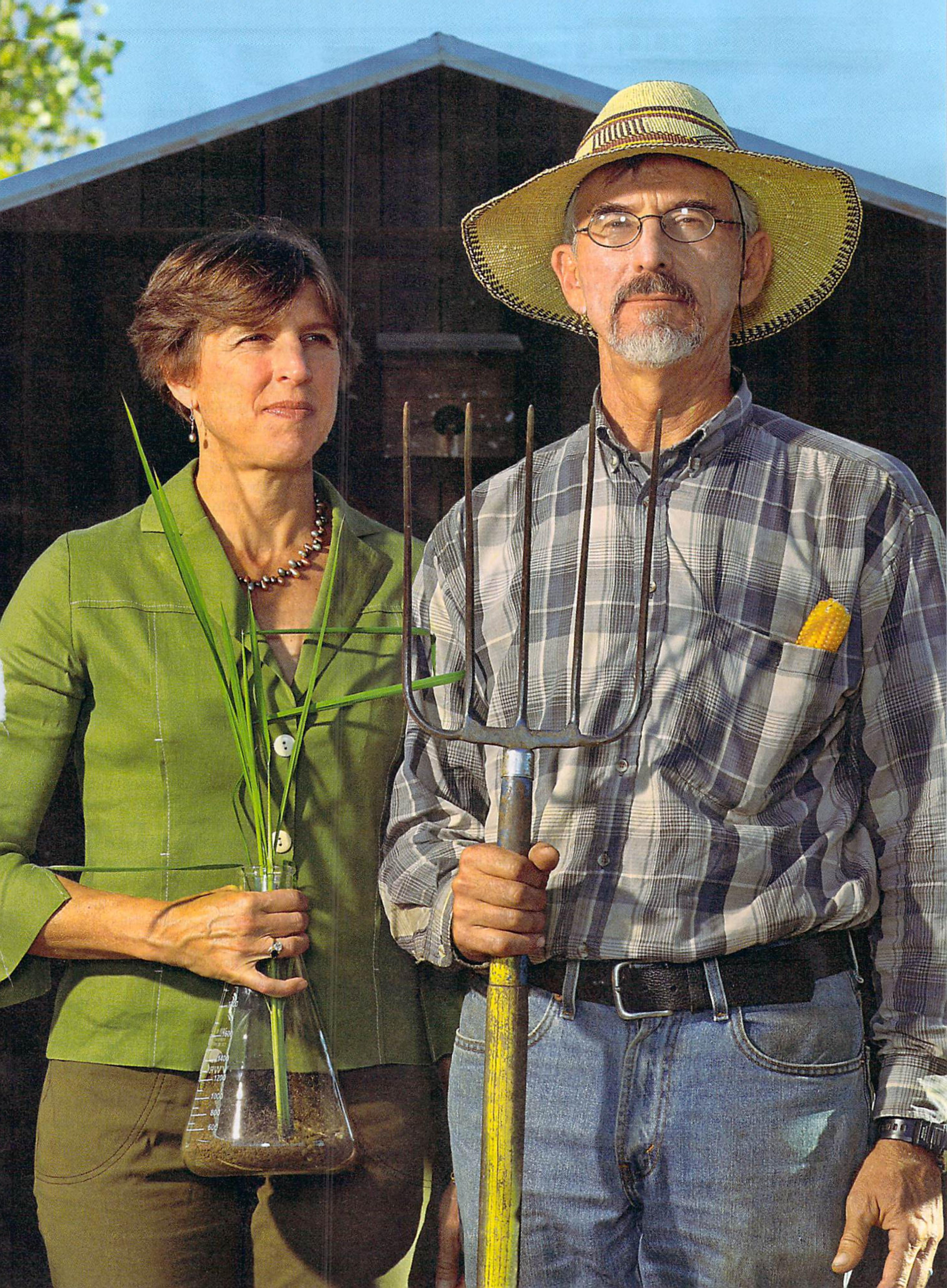


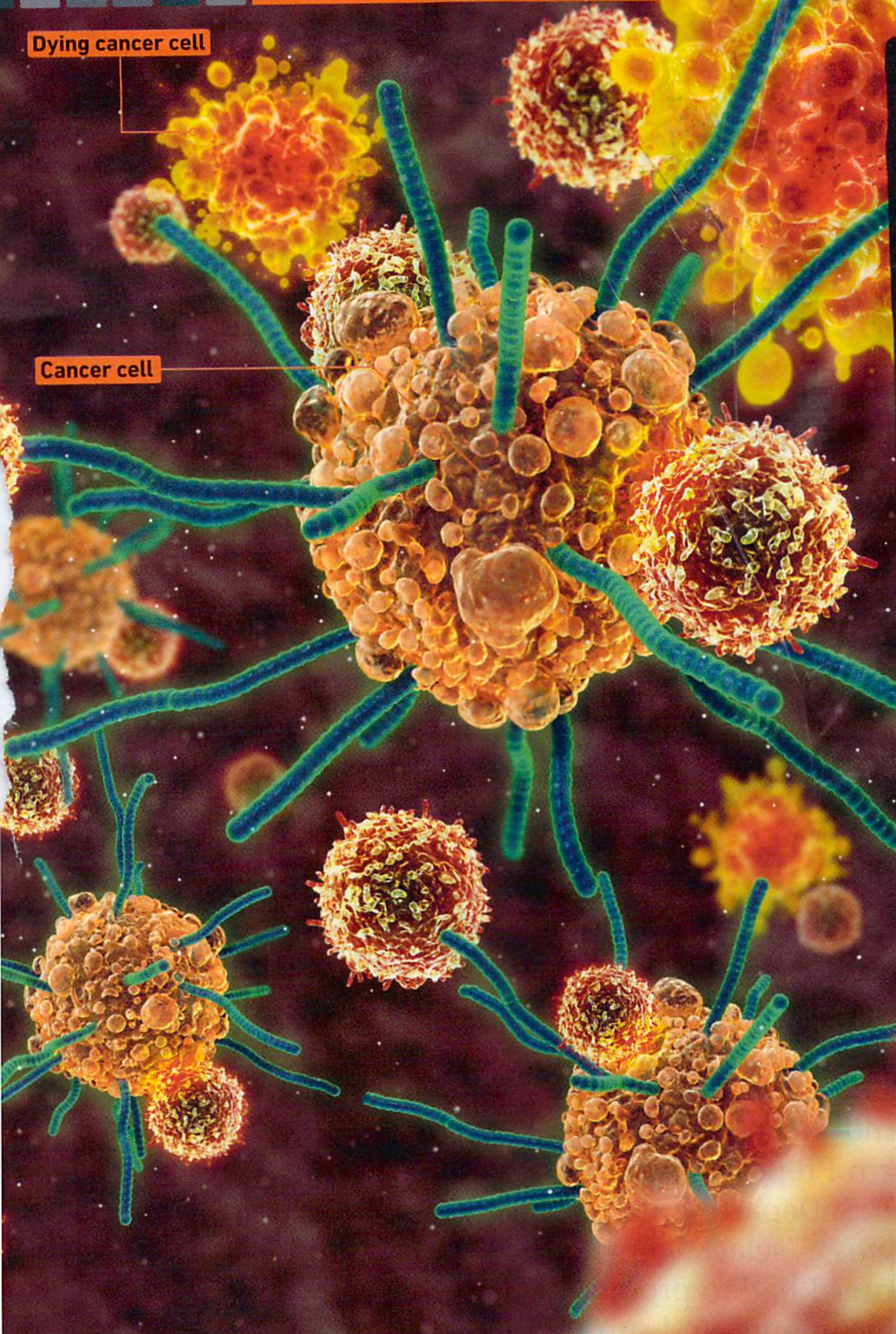
The Second Green Revolution

BY FREDERICK KAUFMAN
PHOTOGRAPHS BY JOHN B. CARNETT

A century of agricultural innovation has vastly increased the amount of food on Earth—and with it, the total population. But the first green revolution is proving unsustainable, and hunger is on the rise. Now keeping the world fed will require an unlikely alliance between genetic engineers and organic farmers

AMONG THE TREE-LINED BIKE PATHS, automated livestock pens and darkened lecture halls of the University of California at Davis, a tiny room holds a weapon of mass destruction. Here, behind locked doors, sits a chunk of *Xanthomonas*, a bacterial blight that has decimated rice harvests in China, India, Indonesia, Malaysia, the Philippines, Thailand, Vietnam and West Africa. Since the passage of the Bioterrorism Preparedness and Response Act of 2002, the U.S. Department of Agriculture has deemed *Xanthomonas* a "select agent," which meant that in order to enter I had to produce a photo I.D., sign a series of documents, and suit up in a disposable lab coat. Within the restricted area, a staff researcher snapped on a pair of rubber gloves, unlocked an incubator, and extracted a petri dish of yellowish goo, which he held a few inches from my outstretched hands. "I can't let you touch it," he said.

AMERICAN GENETIC Scientist Pamela Ronald and her husband, organic farmer Raoul Adamchak, are cultivating a new way to end hunger.



3. ATTACK THE TUMOR

With PAP fragments studding their surface, the primed APCs now serve as the Provenge vaccine. After doctors inject the APCs back into the patient, the APCs circulate in the bloodstream. There, they train the body's **T-cells** to attack any cells that display PAP, including prostate-cancer cells.

FAQs

HOW IS PROVENGE DIFFERENT FROM CURRENT IMMUNE THERAPIES FOR CANCER?

Immune therapies have been around for years. Some provoke a general immune response, like the FDA-approved drug interferon alpha does for leukemia. Others are antibodies—Herceptin binds to breast-cancer cells, hindering their growth. But the effects of those therapies last only as long as they remain in the body. Provenge is the first drug that retrains immune cells to fight cancer after treatment.

WHAT WILL BE THE NEXT CANCER VACCINE TO HIT THE U.S. MARKET?

Two vaccines effective against non-small-cell lung cancer, the most common type of cancer to affect that organ, are the most likely. In a 2004 study, patients who got Stimuvax, manufactured by Merck KGaA, lived on average 17.3 months longer than unvaccinated patients. A similar vaccine by GlaxoSmithKline is also in clinical trials. "Within five years, I think we'll see several more vaccines approved," says James Gulley, a medical oncologist at the National Cancer Institute who is studying a new type of prostate-cancer vaccine called Prostvac. Scientists are currently testing vaccines against ovarian, liver and pancreatic cancers. Several cancer vaccines have already been approved outside the U.S., including ones against skin and colon cancers.

WILL VACCINES EVENTUALLY *PREVENT* CANCER?

Maybe. But giving a vaccine to the masses, including those who would never otherwise get cancer, makes sense only if the vaccine is extremely safe and cheap, Gulley says. Tests for predicting cancer risk could help doctors decide who to immunize.

It may have looked like nothing more than a lump of mold, but the pathogen that could rot the grain that feeds half the world had also introduced a new and ominous twist to the story of mankind's greatest agricultural triumph: the green revolution. Since the days of Thomas Malthus, many scientists have feared that the Earth could not produce enough food to sustain its rapidly growing population. While some contended that science would find a way to overcome such limits, the Malthusians pessimistically maintained that the world possessed a finite amount of arable land and that each acre of that land could produce only a given amount of harvest in a given growing season. Keeping pace with an exploding population meant either creating more land to farm or making the existing farmland more productive. And it was the green revolution that introduced the agricultural breakthroughs that provided the means to do both. Innovations in dam construction and irrigation increased the amount of arable land. At the same time, scientists discovered how to use fossil fuels to create powerful synthetic fertilizers to make that land more productive. Chemists found new ways to battle pests and viruses, and geneticists discovered how to make the plants themselves hardier and more nutritious. More land produced more food, and the result of all this abundance was major, seemingly sustainable population growth. In 1911, when German chemist Fritz Haber first demonstrated how to create synthetic fertilizer, the Earth's population was about 1.7 billion. Since then, it has doubled, and then doubled again.

Now billions of people rely on the continued success of those four innovations: irrigation, fossil-fuel-based fertilizer, chemical pesticides and genetics. But the exorbitant expenditures of resources that guaranteed the success of the first green revolution may no longer be possible. After all, the Malthusians were not wrong about the limits of growth. Today we are rapidly depleting and polluting our sources of freshwater, and much like the planet's population, the price of oil has also doubled and doubled again. Nor can anyone ignore the virulent agri-clouds of insecticide and herbicide, much less the agricultural runoffs that have produced dead zones in our oceans. Of all the green revolution's innovations, only the science of genetics has proved sustainable.

That was why I had come to the Ronald Laboratory, the eponymous workplace of Pamela Ronald, professor of plant pathology and co-author with her husband, Raoul Adamchak, of *Tomorrow's Table: Organic Farming, Genetics, and the Future of Food.* It was becoming clear that maintaining Earth's current population—much less increasing it—would require a second green revolution, and that this next revolution could not draw on the same finite resources as had the first. Scientists must now figure out how to do more with less, and that figuring was going on here, in Professor Ronald's genetics laboratory.

THE DOOR OF THE CONTAGION CHAMBER opened into a large, light-filled room, where Ronald guided me through an antiseptic wilderness of sterilized glassware, centrifuges and fume hoods. The machines rumbled and sputtered and whirred as scientists hunched over their beakers and flasks and test tubes of clear and yellow liquids. To my left, one of a dozen lab researchers and students labored next to a small white box of clear plastic containers labeled "Transformants," while gazing every so often at a document that possessed an arresting single-word title: "Mutant." Here was the act of genetic alteration at its most basic level: the collection and analysis of unprocessed data.

Ronald and her colleagues have deconstructed the genetic code that could prevent *Xanthomonas* and other pathogens from unleashing havoc on the world's food supply, just as they have crunched the molecular numbers to reveal which rice genes will allow a crop to survive catastrophic flooding. In a world beset by drought and hurricane, disease and soil erosion, the science of fighting hunger is becoming an information science, ever less bounded by material limits. If the first green revolution depended on billions of tons of raw materials, the second green revolution will depend on billions of gigabytes of raw data.

Not everyone is welcoming this development. A loose grouping of activists—the local-food movement, the slow-food movement, the family-farm movement, the organic-food movement—perceives genetically altered crops as its nemesis, the embodiment of a corporate agribusiness model that will sweep away

IF THE FIRST GREEN REVOLUTION DEPENDED ON BILLIONS OF TONS OF RAW MATERIALS, THE SECOND GREEN REVOLUTION WILL DEPEND ON BILLIONS OF GIGABYTES OF RAW DATA.

LIFE SOURCE Rice (from top to bottom: callus tissue, protoplasts, and seedlings) sustains the diet of half the people on Earth.

our planet's biodiversity, engender a death spiral of environmental degradation, and increase health risks for consumers at the same time as the largest players in a transnational food cartel use patent law to stash away untold millions of dollars, euros and yuan.

Rather unsurprisingly, research scientists have returned the food activists' scorn with counter-accusations of arrogance, ignorance and elitism. And the entrenched opposition between biologist and foodie has led to the dead end of dichotomy: the widely held notion that a hungry world will have to choose between organic or conventional crops, the past or the future, whole foods or molecules.

Ronald grew up in Northern California, where her hobbies included skiing in the Sierras and cloning her mother's African violets. She has no interest in picking sides. "There are a lot of great ways to minimize the ecological damage done by agricultural systems," she said. "But not all of them are implemented when needed." She showed me a book, *Banana: The Fate of the Fruit That Changed the World* (based, as it happened, on an article that originally ran in Popular Science in 2005). "One hundred million people in East Africa alone rely on bananas for their nutritional needs," she said, but since by far most edible bananas are cloned, the fruit possesses a very limited gene pool, which makes the global banana supply susceptible to obliteration by a single contagion. Many anti-GMO activists had raised alarms about this very problem, and now a banana-killing bacterial disease was making its way through eastern Africa. But Ronald pointed out that her own genetic investigations could be useful in fighting that blight. "Rice is distantly related to the banana," she said, "and our hypothesis is that the same rice gene that gives rice immunity to *Xanthomonas* will function in the banana."

I mentioned the import bans on GM crops that had kept grain from entering Zambia and Zimbabwe even as their citizens suffered through the drought of 2002–3. Would the technology that could create a GM banana also prove to be its downfall? "You want the most appropriate technology for any particular situation," Ronald said. "Everything we care about is embedded in these plant genomes. We would be foolish not to use this information for the public good."

NOT FAR FROM RONALD'S SPOTLESS LAB, her husband and co-author, Raoul Adamchak, treads beneath the open sky. Adamchak has been the farmer-in-chief of the five-acre U.C. Davis student Market Garden since 1996, and it is there that he is enacting a future that at first appears to be precisely contrary to the high-speed, data-driven approach that defines his wife's labors. On this bright summer morning, he was wearing a straw hat from Ghana and muddy farmer boots, and when I asked him about the role organic farms would play in the next green revolution, he did not lead me to a computer screen but to an earthy plot of cowpeas. "The big picture is that in an environmental sense, agriculture is devastating," he said. "Wherever you have crops, you don't have wildlife or native ecosystems or wild plants. You have plants that feed us. So the trick is to make farming as least harmful as possible and still produce a lot of food."

As an organic farmer, Adamchak was especially interested in the molecular workings of carbon, nitrogen, phosphorus and potassium compounds, and the problem of holding these chemicals within the Earth's biomass to feed succeeding generations of crops—rather than allowing them to wash away and fuel unwanted fields of algae that plunder oxygen from the world's lakes, streams and oceans.

Nothing has done more to transform the land, it turns out, than the annual tithe of energy that we demand from it. This energy drain helped create the Dust Bowl of the 1930s and has efficiently wrought a dead zone in the Gulf of Mexico that on some summers reaches the size of New Jersey. And all the efforts of agri-tech could not change the essential fact that everything that grows must first take its energy from the sun, which fuels the photosynthesis that grows the plants, which then die and transfer their energy to the soil, which sustains the crops that eventually fuel the hungry engine that is the human stomach. But conventional agriculture is a terribly inefficient means of transferring energy from sun to stomach. Commercial farmers extract ancient solar energy (that is, oil and other fossil fuels) from one hole in the ground, convert it into fertilizer, transport it across great distances—and then pour it right back into another hole in the ground. This convoluted scheme

FARMERS EXTRACT ANCIENT SOLAR ENERGY (THAT IS, OIL) FROM ONE HOLE, CONVERT IT TO FERTILIZER, TRANSPORT IT ACROSS GREAT DISTANCES—AND THEN POUR IT RIGHT BACK INTO ANOTHER.

IN THE GRAIN At the U.C. Davis greenhouse, transgenic rice carries genes that confer flood tolerance and resistance to blight.

contributes to erosion, wastes considerable energy, and creates pollution at every stage. But cover crops such as cowpeas, Adamchak explained, could help eliminate the farmer's need for synthetic fertilizers. Using a form of bacterial symbiosis, they breathe in nitrogen from the air already around them and fix the molecules in their roots, stems and leaves. When they die, that nitrogen—the all-purpose, basic fertilizer—resolves into the soil. In this way, cover crops help keep the energy cycle local.

I asked Adamchak what he made of the genetic work his wife did. He said that in our closed-loop world of limited resources, where every expansion of fertile farmland demands a corresponding decrease in natural habitat, he and Pamela Ronald had reached a new perspective on the future of food: that it will be neither organic nor molecular but an agro-ecological synthesis of both bodies of knowledge. "As a farmer, I'm not quite sure how healthy it is to look backward for solutions to problems," he said. "A molecular understanding will help solve problems down the road."

I considered a future in which the science of genetic modification exploits all the micro-information available from a plant's genome even as the science of organic farming exploits the macro-energies of the sun, the earth and water. Unlike synthetic fertilizers and chemical pesticides, both the gene and the Earth's energies had always already been there, waiting. Both methods of making food took advantage of what was closest at hand. The farmer interrupted my thoughts as he held out a flimsy green plastic pint basket. "You've got to pick now."

So I bent over a row of tomato vines and worked my fingers through a tangle to reach the grape-size Sun Gold tomatoes, a crop of contradictions. These tomatoes were organic, but they were genetically altered too. And as the ooze from broken stems stuck to my fingertips, I contemplated the entrenched conflict between the activists and the scientists, the mystics and the agribusinessmen. No matter how many advances we make in genetically modifying our seeds, they will still need to be planted in the earth, watered, weeded, ripened, and harvested.

As I walked away from Adamchak's organic garden, I imagined a world filled with thousands of customized, gene-spliced, open-source, freely available grains—some made to resist freeze, others to resist flood, and some to resist deadly rice pathogens like *Xanthomonas*. All of which could conceivably be grown using the organic methods I had just witnessed.

Then, as if to materialize my thoughts, I came across a vast greenhouse. Beneath the great glass roof, full-grown rice plants shot up from black plastic paddies packed with mud and flooded with brown-gold water. The yard-tall flat plants were rough-skinned and pointy-tipped, top-heavy with beautiful green kernels of rice. Each plant had its own label, and I stopped before a particularly tall and vigorous clump called Xa21-106/TP309. This was the first disease-resistant transgenic rice Ronald created, one that she has cultivated in her laboratory for more than a decade. "Many years ago, we gave the Xa21 gene to Chinese breeders," she had told me. "It was scheduled to be released two years ago, but the agricultural ministry still has not approved it."

Today, while the Chinese government bolsters intellectual-property protections for its seed industry, Xa21-106/TP309 still languishes in the ministry's bureaucracy, where it awaits the go-ahead for commercial development. Despite the ravages of Asian rice blight, and despite the fact that the virus has helped add millions to the roster of those who are hungry or starving at this moment, Pamela Ronald's Xa21-106/TP309 has yet to become an officially commercialized crop. If this rice embodied the future of food, what on earth was holding it back?

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THAT EVENING, I MET Ronald and Adamchak at a restaurant tucked into a quiet corner of downtown Davis. We settled around a wooden table surrounded by bottles of rosé and riesling, blanc de blanc and semi-seco, cabernet, port and prosecco. An arrangement of dead wheat sat on the mantle above us, the stalks of yellowed grass tied together and flared like a bouquet of flowers. Our flights of wine arrived in test-tube racks. "It's all a biology experiment," Adamchak said.

As we ate our organic chips and guacamole, Ronald and Adamchak explained that farmers have always modified food genes. Since the days, some 10,000 years ago, when humans first began to save the seeds of one plant variety and discard those of another, they favored the ones that produced the plumpest grains,

GREEN GENES
One result of 10,000 years of agricultural innovation: the planet's farmers can choose from some 120,000 varieties of rice.

the earliest maturities, the highest yields. They also selected hardy specimens, varieties that could withstand the heat and the cold and all the blights that cursed and killed their crops. Even if none of the prehistoric paddy-technologists of, say, China's Yangtze River valley could understand why only the merest sampling of the Earth's increasing varieties of rice did not wilt and die when infected with the stuff that looked like a lump of mold, the blight that eventually came to be known as *Xanthomonas,* these generations of anonymous men and women were nonetheless gathering information and acted on their findings. They were farmers, but they were also seed scientists, consciously transforming wild grasses into harvestable grains.

In 1866, the science of seed selection took a major step forward. A monk named Gregor Mendel compared the characteristics of some 30,000 different pea plants and demonstrated the so-called factors of inheritance, the dominant and recessive genes that form the basis of modern seed hybridization. Mendel's calculations transformed the mysteries of plant lineage and the crapshoot of cross-pollination from guessing games to matters of statistics—a transformation that perfectly suited the times. Soon after Mendel's discovery, news of famine in India hit the London broadsheets, and the perennial fear of global hunger once again began to pervade American and European consciousness. All of which may explain why, when Luther Burbank published his *New Creations in Fruits and Flowers* in 1893, newspapermen dubbed him a "seer." Americans marveled at the geneticist's pitless prune, his spineless cactus and his white blackberry. And when radio eventually bought the rights, "the Man with Green Fingers" was portrayed by none other than Lionel Barrymore. How was it, then, I asked the couple, that genetic modification had become such a villain to so many within the food movement?

As it turned out, Burbank's popular success had far-reaching consequences. The Plant Patent Act of 1930 amended U.S. patent law to provide botanists with economic incentives for their innovations and transformed agriculture from a science based on information to a business based on information. Since the passage of the act, each new variety of crop has made possible an income stream from a new form of intellectual property—property that could be bought, sold, licensed, or monopolized. Eventually the demand for new varieties took on its own logic; hardiness, resistance to pests, and greater nutritional value were still important, but so too was newness itself. Seed manufacturers sought hundreds and thousands of varieties to patent and sell, and they pursued more and more advanced methods of creating the next best seed, including radiation-induced asexual mutation and cloning. Of course, the vast majority of today's supermarket shoppers remain [CONTINUED ON PAGE 87]

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unaware that the science of agriculture is anchored in a project of for-profit genetic improvement.

At that point in the discussion, my grass-fed bison stroganoff arrived, along with our eggplant hummus pizzetas, vegetarian lasagna and an order of sweet corn *cachapas*.

"Almost nothing we eat is found in nature," Ronald said. "In a sense, it's all unnatural."

WHEN DINNER WAS OVER, I still had plenty of questions about our planet's prospective meals. What about that *Xanthomonas* under lock and key, I asked. Where did Xa21 rice come from? And how did gene-altered rice fit into the organic/molecular synthesis the couple envisioned?

The explanation, it turned out, was rooted in basic science. As a graduate student, Ronald had put in a request to the International Rice Research Institute in the Philippines for a sample of a hybrid cultivated from *Oryza longistaminata*, a wild species that had long been gathered by the Bela tribesmen of Mali. *O. longistaminata* tastes lousy and offers unexciting yields, but this particular variety had one thing going for it: It was virtually immune to the lesions of rice blight. Ronald and her colleagues at Cornell University—and then at U.C. Davis—spent the next five years tracking down the precise location of *Xanthomonas* resistance in the hybrid sample. She knew that if she could isolate the resistance gene, her team could eventually insert its sequence into any variety of rice they wished, from long-grained to sticky, sushi or Uncle Ben's—which was just what they accomplished in 1995, when they introduced a gene of *Xanthomonas* resistance into a once widely cultivated glutinous variety called Taipei 309 and created immunity to the ravages of blight where none had been before, immunity that could be passed down from one generation to the next.

Just as the transnational agribusiness giants would have done with such a potentially lucrative breakthrough, Ronald and U.C. Davis filed their discovery with the U.S. Patent and Trademark Office, thus ensuring that this genetic key to *Xanthomonas* immunity would become their intellectual property. Soon thereafter, Monsanto and Pioneer had negotiated an option to license the gene and it looked as though Xa21-enhanced seeds would ▶

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quickly enter the marketplace. But as the U.C. Davis Office of Technology Transfer haggled over the terms for returning the Xa21 gene to the International Rice Research Institute, Monsanto and Pioneer lost interest, and the commercial development of a potentially marvelous technology was frustrated. Disease resistance, it turned out, did not have the same attraction for multinationals as it did for Pamela Ronald, perhaps because Monsanto and Pioneer were already enjoying windfall profits from more lucrative agri-tech innovations, such as "Roundup Ready" crops.

Adamchak downed his last test tube of wine. "Monsanto and Syngenta are taking advantage of patent law," he said, "but I'm hoping that over time, there will be a better understanding of genes and patents and the effect on markets."

In fact, lawyers at the U.S. Department of Justice attempted to clarify some of those issues last fall, when they argued in a brief that no one can own a gene simply because it has been isolated from the rest of a genome. A gene is an element of a law of nature, they said, and a law of nature cannot be patented. But the Patent Office itself has yet to act on the briefing, and so the licensing and sale of genetically modified, mass-produced and mass-marketed seeds continues apace.

Still, just recognizing that a gene may be unpatentable is a useful first step toward achieving the long-term goal of preventing starvation. After all, it is the patent law that allows untold profits for agribusiness giants while demanding acquiescence from small farmers. It is the patent law that has complicated and delayed the commercial planting of Xa21 rice throughout the developing world. And it is the patent law that lurks behind the inequities that have sparked the war between organic and GMO.

As long as the patent law remains as it is, the world's farmers and scientists will benefit from making intellectual property their common ground. Which is why Ronald and U.C. Davis made a special provision as it pertained to their Xa21 rice: They would make the genetic information freely available to less developed countries, while sharing any profits they or their corporate licensees might eventually earn with the impoverished African nation of Mali, birthplace of the gene. In this way, rice could be improved where improvement was most needed, and Pamela Ronald could accelerate the next green revolution. "This is a new time in science," she said. "Things are not happening fast enough."

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