PLANT REVOLUTION

EARTH

By Pamela Weintraub

Imagine grains of rice as big as a fist, or tomatoes and potatoes on a single vine. Have a yen for cheese? Pluck it from the tree under your window. And on that long-awaited trip to Mars, take just enough food for the flight; as you plummet to the Red Planet's surface, you'll see acres of Martian wheat billowing in the breeze.

It may not be long before such dazzling plants dot every field and grove. Scientists at dozens of universities have already begun manipulating plant genes, turning old breeds into new superspecies. At such companies as Monsanto and Du Pont biochemists are designing plants that will fend off parasites and disease. The pharmaceutical industry plans to make a "veggie tranquilizer" with lettuce full of nonaddictive morphine. The Campbell Soup Company has invested $10 million in search of less watery tomatoes and hardier, more productive carrots. And researchers seeking food resources for the Third World are testing crops, looking for ones that would flourish in the barren soil of Subsaharan Africa.

This plant revolution comes in the nick of time. Today more than a quarter of the people on Earth suffer from malnutrition, and millions starve to death each year because they lack affordable food. Complicating matters, world population should double in the next 40 years, forcing us to produce twice as much food just to maintain the status quo.

This vast store of nourishment will have to be grown on less and less land as millions of acres disappear beneath housing developments, highways, and shopping centers. And the soaring cost of fossil fuel, necessary for the production of fertilizer, will push food prices impossibly high, threatening a worldwide famine from which we might never recover.

But plants of the future will help solve these problems: Unscathed by cold and drought, they will span the tundra, the deserts, the Kansas plains. Bursting with proteins and vitamins, they could grow ten times larger than today's crops in the course of only days or weeks instead of months. They would taste better, look prettier, and be easier to digest. Moreover, because these extraordinary new species could produce their own fertilizer, they would require none of the expensive nurturing that is showered on the plants we grow today.

Future plants: Will they obtain beauty from genes that are now found only in birds?

THE MUTANTS ARE COMING

Thanks to James Shepard, of Kansas State University, the first supervegetable to hit the supermarket could be the potato. Shepard, a plant pathologist, has spent the past decade trying to come up with the consummate potato, one that is tasty, nutritious, and resistant to every known plant disease.

From the start, he knew that other scientists had attempted this same feat with conventional breeding—crossing two superior potatoes in the hope of producing a still better offspring. But these researchers soon found breeding better potatoes more difficult than winning the jackpot in Las Vegas. There you get the prize if three cherries line up. But you won't get a great potato unless *50* genes line up, in a *very particular way.* As Shepard points out, "the chances of that happening with conventional breeding are infinitesimally small."

To improve his odds, Shepard decided to manipulate the genes themselves. After experimenting for a few years, he found a way: He could make a potato's genes change spontaneously simply by dissolving its cells in an enzyme solution that removed the hard cell walls. These unwalled potato cells, called protoplasts, mutated 20 times more frequently than normal cells, and the potatoes grown from them were drastically different from the parent potatoes.

Shepard then spent years exposing thousands of tiny potatoes grown from protoplasts to diseases like the deadly blight that caused the Irish potato famine in the mid-nineteenth century. Most of the potatoes died, but a few—the sturdiest, naturally—had mutated so as to develop resistance to disease. These were then cloned into groups of 50 and cultivated in the field.

Last summer Shepard grew 2,300 potato clones on farmland stretching across North Dakota and Colorado. Some

CONTINUED ON PAGE 128

4/82

EARTH

CONTINUED FROM PAGE 14

of the clones were more productive and more resistant to disease than the russet Burbank, considered the finest potato in the United States.

Shepard is now taking his potato work a step further: He is fusing, or combining, protoplasts from entirely different species of plants. His latest creation is a "pomato," the offspring of a potato and a blight-resistant tomato. He doesn't yet know whether the tomato's blight-resistant genes have been transferred to the pomato, but once he has cloned his pomato into 50 or 100 brethren, he'll expose a few of them to blight and see what happens.

PRECISION ENGINEERING

By cloning and fusing protoplasts, Shepard is sure to produce new plant breeds that will boost agricultural productivity in just a few years. But his success, unfortunately, is slow and uncertain, depending on almost random trial and error: Test a million mutant clones, and a few may outdo the conventional plant breeds.

In the long run Shepard's efforts will be superseded by those of genetic engineers who can isolate and modify genes with an ultraprecise technology called recombinant DNA. DNA (or deoxyribonucleic acid) is the chemical that makes up genes. It contains the ultimate, inherited program dictating the characteristics of all living things from animals and plants to the tiniest bacteria. By altering, or engineering, DNA, scientists will be able to custom-design genes from scratch and then insert them into plants to perform specific tasks.

Roger Beachy, of Washington University, in St. Louis, for example, has isolated the gene that instructs the soybean to manufacture its highly nutritious seed protein, "the one that goes into Purina, dog food, and fake steak." He has already cloned the gene in his lab, and his hope is to modify it so it can work in other species; then he will be able to transfer it to relatively productive but unnutritious plants, turning them into food sources. And Joe Key, a biochemist at the University of Georgia, plans to seek the specific genes that allow some plants to withstand heat. He knows, for instance, that extreme heat causes heartier plants to manufacture "survival" proteins, and once he finds the genes controlling production of these proteins, he'll be able to modify them for transfer to virtually any plant alive. The resulting species will be able to survive in searing heat, providing long-sought salvation for farmers near the equator.

HYBRID FANTASIES

Still other scientists hope to create species that are part plant and part animal or bacteria. Biochemists have already transferred human interferon genes to plants. And one researcher, with only minimal whimsy, suggests engineering trees that will grow pork chops; failing that, he says, we could at least make trees that would be the nutritional equivalent of pork, capable of manufacturing proteins now found only in cows or pigs.

In the vanguard of such efforts is Harvard's Fred Ausubel, who began his career in agriculture during the politically turbulent Sixties because of his concern about world hunger. Back then he realized that a likely explanation for the high price of food was the cost of nitrogen fertilizer. He also realized that almost all crop plants needed fertilizer in order to flourish.

The only exceptions were legumes, such as green peas and soybeans, which lived symbiotically with bacteria; the bacteria absorbed nitrogen from the air, then converted it to fertilizing compounds that replenished the legumes. To endow other species with the same good fortune, Ausubel resolved to find the bacteria's nitrogen-converting (or nitrogen-fixing) genes and transfer them to nonlegume crops such as lettuce and corn.

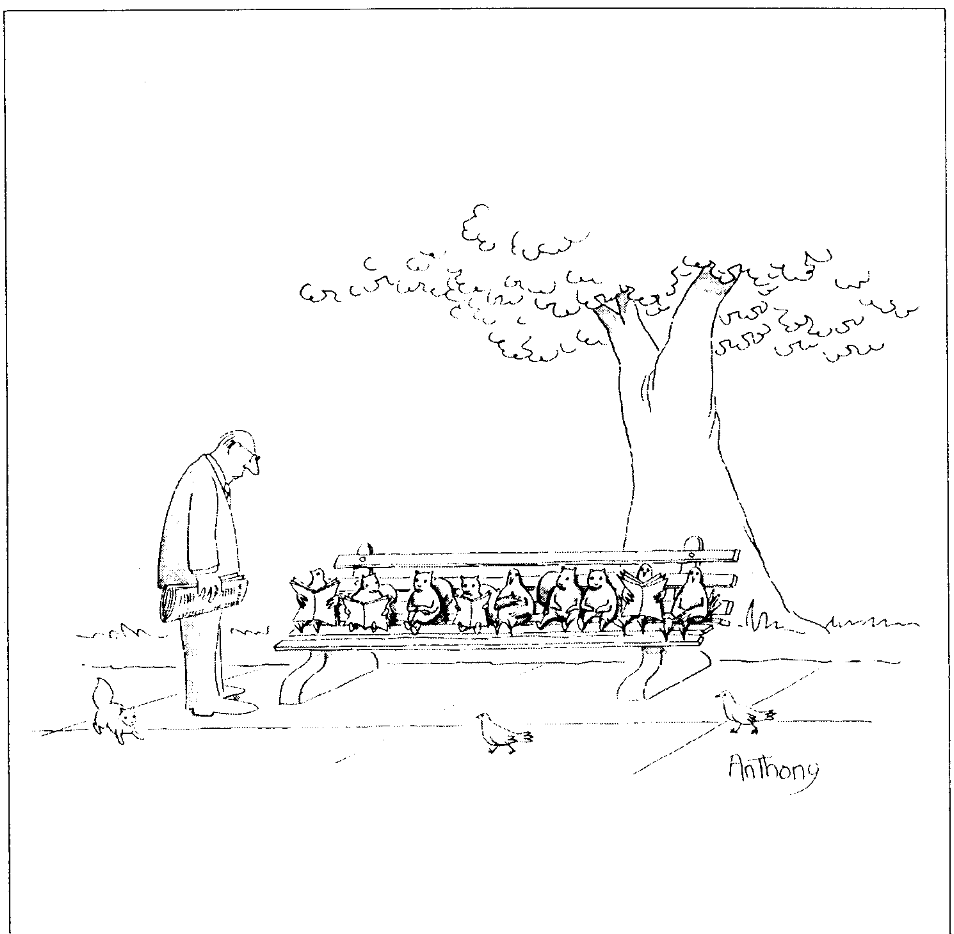
He began by analyzing the strands of DNA in nitrogen-fixing bacteria. Each strand contained thousands of genes, but Ausubel knew that only a few of the genes were required for nitrogen fixation. To ferret out the right ones, he broke the DNA into fragments, then combined each individual fragment with mutant bacteria that he knew *could not* fixate nitrogen. Only one fragment helped these mutant bacteria produce nitrogen compounds, and Ausubel assumed that this fragment contained the nitrogen-fixing genes.

After studying the fragment for a decade, Ausubel has found 17 nitrogen-fixing genes in all. He is now trying to transfer these genes to petunia and tobacco plants, which he hopes will begin fixing nitrogen.

WORKING GENES

This elusive goal—transferring genes to plants and getting them to work—is now within reach because of a stunning series of experiments at the University of Wisconsin. The Wisconsin team got its start two years ago, when biochemist Timothy Hall began analyzing the gene responsible for the French green bean's nutritious seed protein. Before long, Hall's colleague, biochemist John Kemp, decided he would try to put the gene into an ordinary sunflower.

Kemp knew he needed to find a gene ferry—a "vehicle" to carry the bean gene through the swirling liquid of a sunflower cell and into its DNA-packed nucleus. Finally he realized that the bean gene might be able to hitch a ride with a destructive microorganism called *Agrobacterium*, known for its ability to carry cancer-causing genes into the sunflower cell nucleus. Kemp and a third team member, Preabhakara Choudary, transferred the bean gene to agrobacteria, placing it near the cancer genes. Then they injected the bean-treated bacteria into the sunflower.



When the sunflower began producing the biological precursors of bean protein late last summer, genetic engineers around the world were elated. It was obvious that the sunflower had incorporated the bean gene into its own chromosome, becoming the first plant ever to manufacture a substance at the behest of a foreign gene.

To make agrobacteria more practical, Mark van Montague and Jeffrey Schell, of the University of Ghent, in Belgium, have recently found a way to destroy its cancer-causing genes while leaving the rest of the organism intact. Thus, agrobacteria can now transfer genes into sunflowers and other plants *without* inducing cancer.

"The implications," Schell says, "are astounding. For the first time we can endow plants with new genes—and new traits—that are transmitted from one generation to the next. We have the ability to put *any* gene we want *anywhere* we want it."

PLANTS UNLIMITED

The promise of the plant revolution seems limitless, but every miracle has its cost. Because its success requires vast and costly field experiments, this brave new world of agriculture will be controlled by the Du Ponts and the Monsantos, not by the plant breeder on the farm. "In time," says Jack Doyle, of the Environmental Policy Center, in Washington, D.C., "America's farms could come under contract to the laboratory-based corporations, using corporate-bred plants, chemicals, and hormones." These large companies, interested in making a profit, might pay more attention to a plant's color than to its vitamin content. "The historical lessons of corporate irresponsibility on pesticides, toxic wastes, and carcinogens should be all too fresh in our memory," Doyle warns, "to allow another, more insidious form of corporate dominance to emerge."

Another fear is that scientists might make a mistake, creating genetically engineered "monsters" with dangerous new qualities. Such plants might be extremely susceptible to crop blight or might carry substances harmful to the people or animals that eat them. Once such a plant is widely distributed, its growth will be almost impossible to halt.

With extra care and an awareness of the pitfalls, however, scientists can make the good outweigh the bad. When the first fruits of biotechnology move from the lab to the farm, sometime around 1990, Americans will start producing superabundant stores of superior crops for a fraction of the cost. And Third World farmers will wage war against some of their worst enemies—insects, plant disease, and soil that has too much salt or too few minerals. By the year 2000 these farmers will have access to hearty, inexpensive crops containing every nutrient craved by their malnourished countrymen. Mankind will have its first potent weapon against starvation and the means to provide affordable food for all the people of the world. ∞