plants to create a green cleanup crew, in this case for mercury, a lethal waste product found at various industrial sites. Microbes in soil and aquatic sediments transform the element into methyl mercury, which is a particularly serious problem because it accumulates in the food chain and causes neurological damage in humans. A few years ago Meagher made use of a bacterial enzyme, mercuric ion reductase, that converts ionic mercury in mercuric salts to the elemental form, the least toxic form of mercury. When this gene was placed in *Arabidopsis*, canola, tobacco, and even yellow poplar, it allowed the plants to grow on mercury-laden media and release the metal into the air. By eliminating mercury from these sites, the plants block the formation of methyl mercury.

Some might cringe at the notion of plants emitting trails of mercury vapor, but Meagher argues that, compared to the global pool of mercury in the air, the amount emitted from contaminated sites would be a trace. And he has an additional strategy for cleaning up mercury contamination. Last month, he and his colleagues reported in the *Proceedings of the National Academy of Sciences* that they had endowed *Arabidopsis* with a second modified bacterial gene that enabled the plants to break down methyl mercury directly. The gene, encoding an organomercurial lyase, catalyzed the split of the carbon-mercury bond, releasing less-toxic ionic mercury. Meagher hopes that the same enzyme can be engineered into trees, shrubs, and aquatic grasses, allowing these plants to detoxify dangerous methyl mercury. "Our working hypothesis is that the appropriate transgenic plant, expressing these genes, will remove mercury from sites polluted by mining, agriculture, and bleaching, for example, and prevent methyl mercury from entering the food chain," says Meagher.

Pakrasi cautions, however, that before transgenic plants can be widely planted on contaminated soils, researchers will need to do extensive field trials. Transgenic plants adept at handling metals in laboratory and greenhouse experiments may not perform as well when the soil, moisture, and climate vary, for example. "There are a lot of unknowns," Pakrasi says. **–ANNE SIMON MOFFAT**

NEWS

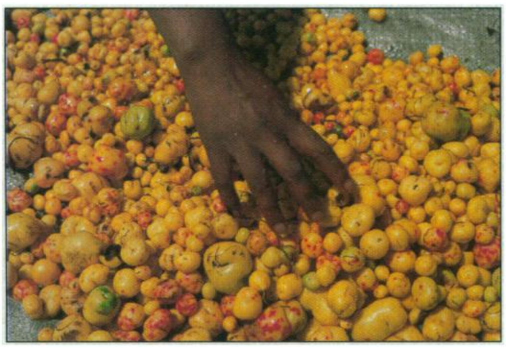
Crop Engineering Goes South

The staple crops of the developed world—wheat, corn, rice, and soybeans—get most of the attention from genetic engineers, who are endowing them with genes for resistance to disease and herbicides. Now some researchers are turning their attention to so-called nonprimary crops, often native to the subtropics or tropics, that have untapped potential for producing food, fiber, fuel, and medicines. One such crop, sweet potato, has already been genetically altered to improve its protein quality and may soon be planted commercially (*Science*, 18 December 1998, p. 2176). Enhanced versions of other crops that produce food or products for export in the developing world are in the pipeline.

Bringing the Potato Back Home

Although potatoes are everywhere in the Western diet—baked, fried, and made into chips and starch thickeners—per capita consumption is relatively low in developing countries, even in South America, where the crop originated. The problem? The huge gains in U.S. yields—a doubling over the last 50 years, achieved via classical plant breeding and irrigation, pesticides, and fertilizers—have been made with potatoes that cater to U.S. tastes and climate. But genetic engineering could allow the developing world to close the gap.

At last May's China Workshop on Plant Biotechnology in Beijing, Alejandro Mentaberry of the Research Institute of Genetic Engineering and Molecular Biology in Buenos Aires announced that researchers there had modified potato types commonly grown in Chile, Argentina, Uruguay, Cuba, and Brazil. Using *Agrobacterium* as a gene shuttle, the researchers created 16 transgenic lines, each carrying a different two-gene combination coding for resistance to various viral, fungal, and bacterial diseases. Several of the transgenic lines, which express antimicrobial proteins such as lysozyme and attacin from the giant silk moth, are resistant to the *Erwinia* bacterium, a serious potato pathogen, and are being field tested in Chile and Brazil.

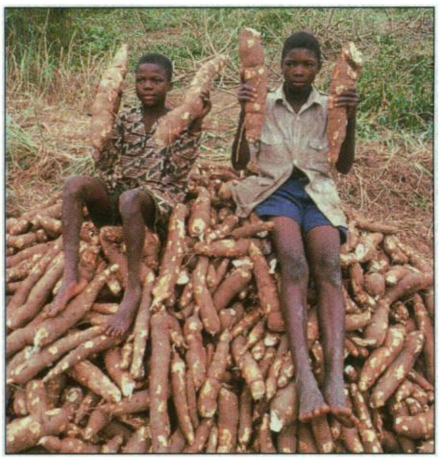


Spuds of the Andes. Yellow potatoes in Ecuador.

A consortium of 13 Latin American and European laboratories now hopes to introduce an array of six genes—for resistance to various fungal, bacterial, and viral pests, for herbicide resistance, and for the natural insecticide *Bt* toxin—into a single tropical cultivar. Some researchers worry that such a heavy load of foreign genes will depress yields. Indeed, a single gene for an insecticidal toxin may have reduced yields when it was added to another strain of potatoes tested in upstate New York. But Roger Beachy, president and director of the new Donald Danforth Plant Science Center in St. Louis, who has put 14 genes into one rice strain, says: "I'm optimistic about their goals. The precedent for that sort of project is pretty good."

A Healthier Cassava

Known to Western societies as a source of tapioca, cassava is a mainstay of the developing world's diet. The leaves and starchy roots of this shrub, when powdered, boiled, fried, or fermented, make up the world's third largest source of calories, after rice and corn. About 60 years ago, British scientists working in East Africa began a program of plant breeding to increase the size and number of edible roots. Yields improved at first, but over the years the gains plateaued in the face of increasing losses to fungal, viral, and bacterial diseases. Now scientists are trying to push up yields again with the tools of biotechnology.



Rooting for sustenance. Freshly dug cassava.

The impetus comes from three organizations: the International Laboratory for Tropical Agriculture and Biotechnology (ILTAB), originally based in La Jolla, California, but now moving to the Donald Danforth Plant Science Center in St. Louis; CIAT (the Center for International Tropical Agriculture) in Cali,

CREDITS: (LEFT TO RIGHT) WALT ANDERSON/VISUALS UNLIMITED; SYLVAN WITTWER/VISUALS UNLIMITED

Colombia; and the Cassava Biotechnology Network, a federation of small companies, scientists, and cassava growers. They joined forces about 10 years ago and, as a first step, set out to map the cassava genome—a continuing effort that has now produced about 300 markers. In 1995 ILTAB researchers also developed techniques for introducing foreign genes into cassava cells with *Agrobacterium* and gene gun technology, then regenerating transformed cells into whole plants.

These transforming systems are "not yet routine," says ILTAB director Claude Fauquet. Still, researchers have already succeeded in transforming cassava with a truncated protein produced by the gemini virus, which makes the plant resistant to the African cassava mosaic virus by an unknown mechanism. They have also created disease-resistant cassava plants by introducing a gene that expresses replicase, an enzyme that disrupts the life cycle of invading viruses.

If these and other efforts succeed in the field, cassava yields could increase 10-fold, to 80–100 tons per hectare, says Fauquet. But he says the effort is too small to pay off quickly. Cassava, he says, "is a poor crop in terms of those studying it, commanding the attention of only about 50 scientists worldwide. But it is rich in potential for feeding the developing world."

Richer Oils From a Palm

One target of agricultural biotechnology could bolster the developing world's foreign exchange as well as its food resources. Just last month, Massachusetts Institute of Technology microbiologist Anthony Sinskey and colleagues at the Palm Oil Research Institute of Malaysia (PORIM) launched a multimillion-dollar project to genetically engineer the oil palm to produce everything from improved oils to, conceivably, biodegradable plastics.

The palm, which prospers on plantations in Malaysia, Indonesia, and Central America, produces eight to 10 times more oil per hectare than canola or soybean, the top oil producers in temperate climates. And the market for the oil could expand if genetic engineers could redirect enzymatic pathways to produce an oil richer in oleic acid, which goes into cooking oils, or stearic acid, used as a cocoa butter substitute and a raw material for soaps and shaving creams.

Over the past decade, Malaysian researchers have learned how to regenerate palms from cell culture, a necessary step in producing a transformed plant from a single genetically engineered cell. And 2 years ago, PORIM's Suan-Choo Cheah and G. K. Parveez successfully shot a gene for herbicide resistance into cultured cells with a gene gun, then generated transformed palm seedlings. The next step, says Sinskey, is to try modifying the biochemical pathways that produce the oil.

Sinskey, a pioneer in identifying genes for natural polymers, is even thinking of engineering oil palms to produce natural polyester compounds that could serve as biodegradable plastics, as a number of researchers have done with *Arabidopsis*, soybean, or canola. Because palms are so productive, Sinskey says, they might have a better chance of making plastics economically.

Oil on tap. Harvesting oilseed in Cameroon.

Still, palms aren't an easy target for genetic engineers. Unlike annual row crops, such as corn and soybean, palms take a long time to show results. Once a seed is planted, it takes 3 to 5 years to get first oil production. "You can't get three plant generations per year, as you do with corn," says Monsanto's Steve Lehrer, who heads that company's specialty crops research. And palms generated from single cell culture aren't always vigorous. Even so, says Sinskey, "I am quite confident that palms can be genetically manipulated."

A Better Banana

To the Western world, bananas and their close relatives, plantains, are a snack and dessert. But in western and central Africa, they provide more than one-quarter of all food calories, and they feed tens of millions in Central America and Asia, too. Indeed, the United Nations Food and Agriculture Organization ranks bananas as the world's fourth most important food crop. But despite their economic importance, they have received only erratic study. Tropical species have not been a top priority for crop scientists in the developed nations, and bananas are a difficult challenge for traditional plant breeding. Bananas produce fruit without pollination and reproduce vegetatively, and almost all important banana cultivars have three sets of chromosomes, making it difficult to add desirable traits by classical breeding.

Now genetic engineers are finding that they can bypass those obstacles by slipping new genes directly into the banana genome. Ultimately they hope to create plants resistant to the fungal diseases that threaten this staple, and also to engineer in genes for foreign proteins that, when eaten, act as antigens, creating edible vaccines.

"Today, banana research is where rice research was in 1990," says plant biologist Charles Arntzen of the Boyce Thompson Institute for Plant Research (BTI) in Ithaca, New York. Researchers have just learned how to introduce foreign genes into the plants, a step that four groups reported at last spring's First International Symposium on the Molecular and Cellular Biology of the Banana, held at BTI. One group, from Australia, used a "gene gun" to inject DNA coding for several marker genes into tissue from the Cavendish banana—a dessert variety that is widely exported—which grew into plants expressing the genes. Three other international teams used the plant bacterium *Agrobacterium*, which injects DNA into cells it infects, to insert marker genes into various banana types.

Researchers at the Catholic University Leuven in Belgium have now gone a step further, introducing genes encoding antimicrobial proteins into banana cells to generate plants resistant to *Mycosphaerella fijiensis*, the most serious fungal disease of banana. Says Randy Ploetz of the University of Florida, Gainesville, "An engineered banana may be produced in the near future that will resist at least some fungal diseases."

Arntzen and colleagues are also hoping to engineer bananas to produce antigens so that they can be used as edible vaccines against diarrhea caused by *Escherichia coli* and the Norwalk virus. Last year, he, Hugh Mason, and their BTI colleagues demonstrated the principle when they transformed potatoes to produce an *E. coli* protein, which elicited immune responses in human volunteers who ate the raw potatoes; they now have similar, unpublished results with potatoes and the Norwalk virus. But bananas are a better vaccine medium, Arntzen says, because raw bananas, unlike raw potatoes, are tasty.

Tahitian feast. Bananas, plantains, and taro root.

—ANNE SIMON MOFFAT

CREDITS: (LEFT TO RIGHT) JANE THOMAS/VISUALS UNLIMITED; J. R. WILLIMAS/EARTH SCENES