ANDY CRAWFORD *Getty Images*

Breeding Cassava

The world's third-largest source of calories has the potential to become a more productive and more nutritious crop, alleviating malnutrition in much of the developing world

By Nagib Nassar and Rodomiro Ortiz

KEY CONCEPTS

- Cassava roots are the main source of calories for millions of people living in the tropics, but they are poor in protein, vitamins and other nutrients.
- Scientist have created cassava varieties with improved nutritional value, higher yields, and resistance to pests and disease.
- A combination of traditional breeding, genomics and molecular biology techniques could lead to further breakthroughs.

—The Editors

The diet of more than 800 million people revolves around neither wheat, nor corn, nor rice. Instead in many countries the main staple consists of the starchy roots of a plant variously called cassava, tapioca, manioc or yuca (not to be confused with the succulent plant yucca). Indeed, cassava contributes more to the world's calorie budget than any other food except rice and wheat, which makes it a virtually irreplaceable resource against hunger. Throughout the tropics, families typically cultivate it for their own consumption on small parcels of land, although in Asia and in parts of Latin America the plant is also grown commercially for use in animal feed and starch-based products. The root's nutritional value, however, is poor: it contains little protein, vitamins or other nutrients such as iron. Better varieties of cassava could thus effectively alleviate malnutrition in much of the developing world.

Because of that promise, the two of us and our colleagues at the University of Brasilia and others are devoted to creating hardier, more productive and more nutritious varieties and

to Feed the Poor

making them widely available to farmers in developing countries. Our team focuses largely on applying traditional breeding techniques to form hybrids between cassava and its wild relatives, taking advantage of traits that have evolved in the wild plants over millions of years. This approach is less costly than genetic engineering and does not raise the safety concerns that make some people wary of genetically modified crops. Meanwhile researchers and nonprofit organizations in the developed world have begun to take an interest and have produced genetically modified cassava varieties for the same purposes. The recent completion of a draft genome sequencing of cassava may open the way to further improvements.

Tropical Favorite

The shrubby plant *Manihot esculenta*—the scientific name for cassava—and its wild relatives of the genus *Manihot* originate in Brazil. Indigenous peoples first domesticated the plant, and Portuguese sailors took it to Africa in the 16th century; from there its use spread to tropical Asia, reaching as far as Indonesia. Africa now produces more than half (51 percent) of the world's annual output of more than 200 million metric tons; Asia and Latin America harvest 34 and 15 percent, respectively.

The roots, resembling elongated sweet potatoes, can be eaten directly, either raw or boiled, or can be processed into granules, pastes or flours. In Africa and some parts of Asia, people also consume the leaves as a green vegetable, which provides protein—a dry cassava leaf is up to 32 percent protein—and vitamins A and B.

Cassava requires low investment in capital and labor. It tolerates drought and acidic or infertile soils fairly well; quickly recovers from damage caused by pests and diseases; and is efficient at converting the sun's energy into carbohydrates. In fact, whereas the edible part of grain

[WORLDWIDE PRODUCTION]

Who Grows Cassava?

Cassava is a favorite of subsistence farmers throughout the tropics and especially in Africa, where more than half of production is concentrated. The plant grows easily from small cuttings and tolerates drought and infertile soils. Its roots can be pulled out at any time of the year for a quick calorie fix. Like noodles, bread or rice, it accompanies dishes that are as varied as the local cuisines. In some countries it is also grown commercially.

crops is at best only 35 percent of the plant's total dry weight, in cassava it is about 80 percent. Moreover, cassava can be planted at any time of the year, and harvesting can be delayed by months or even by a year. Thus, farmers often keep some plants in the field as a kind of insurance against unforeseen food shortages. It is no wonder that the crop has become a favorite of subsistence farmers in nearly every region where it can grow and that it has become an integral part of local traditions and cuisines.

The crop, however, has disadvantages as well. It has a short shelf life, and if unprocessed, it usually goes bad within a day. Moreover, cassava plants within a given region tend to be genetically uniform, which makes crops vulnerable: a disease or pest that damages one plant will likely sicken them all. But most of all, the lack of nutrients other than carbohydrates makes cassava a risky food to rely on excessively.

Hybrid Technology

One of us (Nassar) first became interested in improving cassava as a young agronomist in his native Egypt. In the early 1970s—a time of widespread famines in sub-Saharan Africa—he visited Brazil to study the plant in its original environment. He then decided to relocate, eventually becoming a naturalized Brazilian. In 1975 at the University of Brasilia, with a small grant from Canada's International Development Research Center, he began to assemble a living collection of wild *Manihot* species, which could serve as a library of useful traits that could be added to cassava. Traveling the country, often on foot or by bicycle, he collected specimens and took them back to Brasilia, where he and his collaborators would eventually grow 35 different species.

This biodiversity resource would prove crucial in the development of new varieties, both at the university and elsewhere. One of the first results achieved by the team was the creation in 1982 of a hybrid breed with higher protein content. Cassava roots are typically just 1.5 percent protein, compared with wheat's 7 percent protein or more. In particular, the roots are deficient in sulfur-containing essential amino acids such as methionine, lysine and cysteine. The new hybrid variety had up to 5 percent protein content. The Brazilian government is now seeking ways to reduce the country's dependence on foreign wheat by adding cassava flour to wheat; using higher-protein cassava would help preserve the daily

ROOM FOR IMPROVEMENT

Although cassava is a readily available source of calories for many of the world's poor, excessive reliance on it can lead to malnutrition. In particular, it is a poor source of protein, vitamins A and E, iron and zinc. The plant has other shortcomings:

- It is highly perishable if not processed.
- It is usually planted from cuttings, leading to genetic uniformity and to vulnerability to pests and diseases.
- Certain varieties, if not cooked properly, can cause cyanide poisoning, leading to paralysis and death.

MAPPING SPECIALISTS; SOURCE: FOOD AND AGRICULTURE ORGANIZATION (*map*); GETTY IMAGES (*tapioca starch*); COURTESY OF NEIL PALMER *CIAT* (*bowl of cassava starch*); ANDRE BARANOWSKI *Getty Images* (*boiled yuca*) intake of protein for millions of Brazilians.

Hybridization between cassava and wild relatives, as well as selective breeding between different strains of cassava, may also help create varieties containing other important nutrients. The Brasilia team has shown that certain wild *Manihot* species are rich in essential amino acids, iron, zinc, and carotenoids such as lutein, beta-carotene and lycopene. Beta-carotene in particular is an important source of vitamin A, a lack of which results in progressive eye damage—a serious and widespread problem in the tropics of Africa, Asia and Latin America. Given cassava's status as a staple in the tropics, high-carotenoid varieties could contribute significantly to solving vitamin A deficiencies in the developing world. In the past three years the team has bred highly productive cassava varieties containing up to 50 times as much beta-carotene as regular cassava, and it is now in the process of testing these varieties with local farmers.

Another major project has focused on changing the plant's reproductive cycle. Cassava's ordinary mode of reproduction, by pollination, produces seedlings of types not identical to the mother plant and frequently lower in yield. Farmers thus commonly plant cuttings from existing plants rather than sowing seed. Cutting, however, enables viruses and bacteria to contaminate a plant. Generation after generation, the microorganisms accumulate, which eventually can impair a plant's yield. Like many other flowering plants, certain wild *Manihot* species, including the treelike relative of cassava *M. glaziovii,* procreate both sexually and asexually, and the asexually produced seeds sprout into plants that are basically clones of the mother plant. Through more than a decade of efforts focused on interspecies breeding, the Brasilia researchers recently obtained a cassava variety that can reproduce both sexually and asexually, by making two types of seeds, just like its wild relative. Once further work is completed, this variety will be ready to be distributed to farmers.

M. glaziovii possesses other useful genes that may help feed millions of people living on arid land. A hybrid of *M. glaziovii* and cassava typically displays two types of roots. Some, like those in cassava, swell up with starch and are edible. The second type of root reaches farther underground, where it can tap into deeper water sources. These traits make the hybrids among the best cassava varieties for use in semiarid regions, such as northeastern Brazil or certain of the savanna regions of sub-Saharan Africa. Some have shown tolerance to drought when tested by farmers in Petrolina, one of the driest regions of Brazil. The team is now improving these hybrids to combine high yield and tolerance to drought by backcrossing them with a productive variety of cassava and then selecting high-yield offspring that can be distributed more widely.

A different kind of manipulation—the time-honored technique of grafting—offers another way to increase yields of cassava's tuberous roots, as Indonesian farmers first discovered in the 1950s. Grafting stalks of species such as *M. glaziovii* or *M. pseudoglaziovii* (or hybrids of the two) onto cassava stocks has increased root production in test plots as much as sevenfold. Unfortunately, in many countries the practice of grafting is hampered by the lack of availability of these hybrids.

Pest Insurance

Beyond enhancing nutrition and production, selective breeding and crossbreeding with wild species have been crucial in counteracting the

[THE AUTHORS]

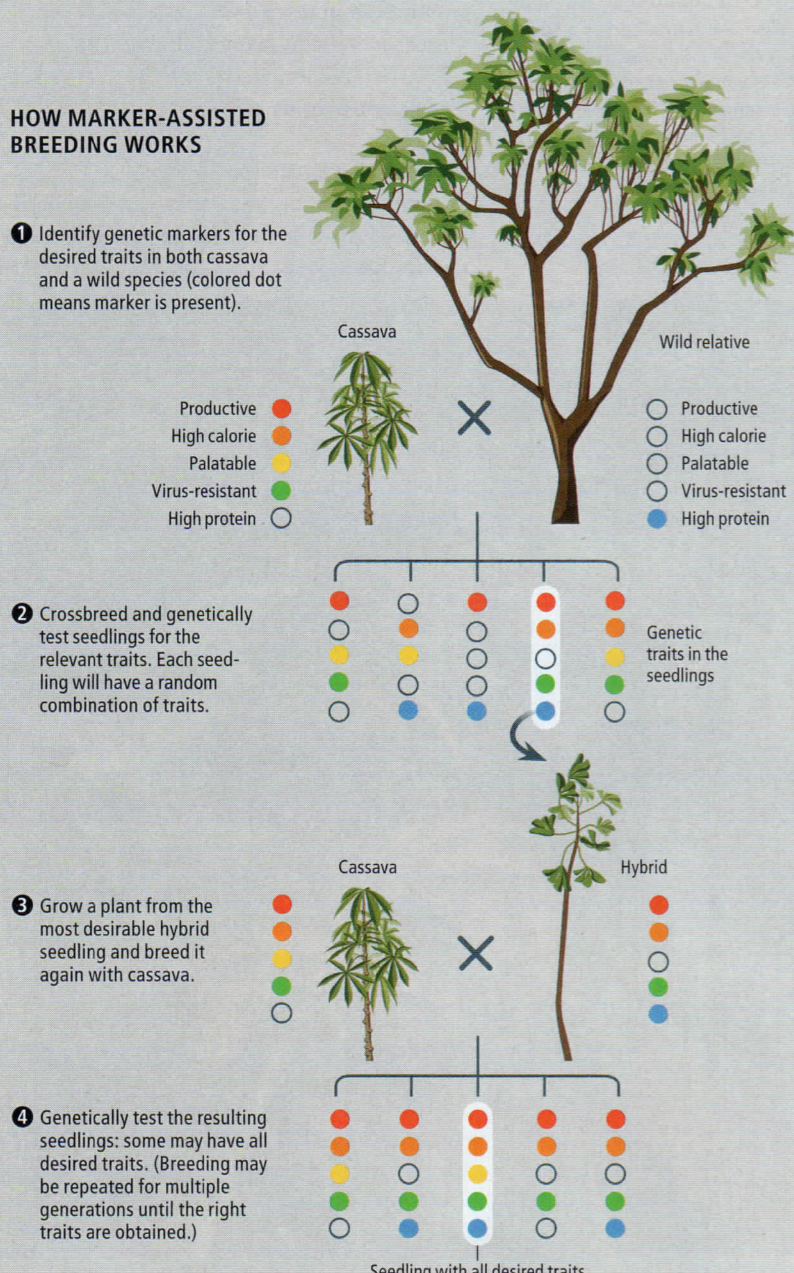
Nagib Nassar, a native of Cairo, has a Ph.D. in genetics from the University of Alexandria in Egypt. He has researched cassava at the University of Brasilia since 1975, creating varieties that have been adopted by farmers in Brazil and exported to cassava breeders in Africa. Rodomiro Ortiz was born in Lima, Peru. He received a Ph.D. in plant breeding and genetics from the University of Wisconsin–Madison and is a former director of resource mobilization at the International Maize and Wheat Improvement Center in Texcoco, Mexico.

CASSAVA FARMER checks his crop in Huila in the Colombian Andes.

[CONVENTIONAL BREEDING]

Ancient Meets Modern

Wild relatives of cassava, including the treelike *Manihot glaziovii* (*left*), often have traits that would benefit the crop but lack many of the desirable traits of the domesticated species. In the time-honored technique of backcrossing, breeders obtain the right combination of all traits by producing many generations of hybrids, often aided by modern tools such as genetic markers, which reveal the presence of a trait in a seedling without the need to grow it into a plant.



spread of pests and diseases. Improving resistance to the cassava mosaic virus ranks among the most important achievements in cassava science. In the 1920s the spread of the mosaic virus in the East Africa territory of Tanganyika (now Tanzania) triggered a famine. Two English scientists working in Tanzania hybridized cassava with *M. glaziovii*, saving the crop after about seven years of efforts. In the 1970s mosaic came back and threatened areas in Nigeria and Zaire (now Democratic Republic of the Congo). Researchers at the International Institute of Tropical Agriculture (IITA) in Nigeria used *M. glaziovii* and its hybrids originating from the University of Brasilia's collection and again produced mosaic-resistant cassava. That newly bred variety gave rise to a family of mosaic-virus-resistant varieties now cultivated on more than four million hectares in sub-Saharan Africa; in the intervening decades, Nigeria has become the world's top cassava producer. Still, viruses undergo frequent genetic mutations, and someday new mosaic strains will likely break the resistance bred into the cassava varieties. Hence, preemptive breeding will always be necessary to stay ahead of the disease.

The cassava mealybug (*Phenacoccus manihoti*) is one of the most virulent pests besetting this crop in sub-Saharan Africa. This insect, which kills plants by sucking out their lymph, was especially devastating in the 1970s and early 1980s; it destroyed plantations and nurseries to such an extent that production virtually came to a halt. Toward the end of the 1970s the IITA and research partners elsewhere in Africa and in South America introduced a predator wasp from South America that lays eggs in mealybugs, so that the wasp larvae eventually devour the mealybugs from the inside. As a result of this effort, the cassava mealybug was held in check across most of Africa's cassava-producing areas in much of the 1980s and through the 1990s. In a few small areas of Zaire this system did not work well because of a rise in the parasite wasp's own predators. In the middle of the past decade the Brasilia team searched wild *Manihot* species for a reliable solution to this problem and found mealybug-resistance traits—once again in *M. glaziovii*. Mealybug-resistant varieties are now grown by small farmers in the region surrounding Brasilia and can be exported to other countries should the mealybug plague come back.

Looking ahead, we anticipate that new, valuable traits could come from breeding chimeras. A chimera is an organism having two or more

JESSICA HUPPI (*illustrations*); COURTESY OF FOREST AND KIM STARR (*photograph*)

[GENETICALLY MODIFIED CASSAVA]

The Biotech Way

Genetic engineering, now widely adopted in U.S. agriculture, is beginning to show results in cassava as well. But genetically modified versions are unlikely to become widely available soon, and some worry that research funding is giving short shrift to cheaper, more traditional methods of developing new varieties.

Major advances have come from an international collaboration called BioCassava Plus. The group has created varieties of cassava rich in zinc, iron, protein, beta-carotene (a source of vitamin A) and vitamin E by using genes from other organisms—including algae, bacteria and other plants.

"We hit our target," says BioCassava Plus lead researcher Richard Sayre of the Donald Danforth Plant Science Center in St. Louis. All the new transgenic varieties are now in field trials on test plots in Puerto Rico, and the program has received the green light to start field trials in Nigeria. Traditional breeding can get beta-carotene into cassava, he says, but for iron and zinc only genetic engineering has shown results so far. Meanwhile Sayre's team is working on combining all the new traits into a single variety.

The project is funded by the Bill & Melinda Gates Foundation and by Monsanto. (Monsanto's support came with strings attached: the corporation reserves the right to charge for the use of the varieties if a farmer's gross income exceeds $10,000 a year.)

GENETICALLY MODIFIED cassava seedlings

Peter Beyer of the University of Freiburg in Germany calls the BioCassava Plus achievements a breakthrough. "The step from here to the product, however, is still a big one," he adds. Beyer should know: the beta-carotene-rich "golden rice" that he and his collaborators first announced in 2000, making the cover of *Time,* is only now nearing approval in several countries. Engineering new organisms may be fast, he notes, but demonstrating that they are safe for the environment and for consumption and breeding them into varieties that are palatable to local tastes is not: 10 to 12 years is the norm. "Regulators simply do not allow you to proceed as quickly as with a variety that has been bred traditionally," Beyer says.

Beyond not necessarily being faster than conventional breeding, genetic engineering is also much more expensive, and sometimes genes that work well in one organism do not work quite as well in a completely different one. "A lot of people have kind of drunk the Kool-Aid" about genetic engineering's promise, says Doug Gurian-Sherman of the Union of Concerned Scientists. Consequently, it tends to get a disproportionate amount of research funding. "I think to put all your eggs in one basket is a huge mistake," he remarks, adding that public funding agencies should help restore a balance. *—Davide Castelvecchi, staff editor*

genetically distinct tissues growing within it. There are two principal types of chimera. In sectorial chimeras, two different longitudinal sectors of tissue are visible in a plant organ, but their growth is not stable, because one of the tissues grows faster than the other and may soon occupy the entire shoot. In the second type of chimera, called periclinal, the external part of the shoot surrounds the internal one and may be more stable than a sectorial chimera. Trials are under way at Brasilia to develop a method of grafting that will produce stable periclinal chimeras using tissue from *M. glaziovii.* Such an approach may lead to continuous root enlargement every time a chimera stalk is planted. Chimeras have so far shown promising productivity and seem to adapt especially well to semiarid areas.

Cassava should be a high priority of agricultural science, but traditionally it has not been. Only a handful of research laboratories have studied this plant, perhaps because it is cultivated in the tropics, far from where most scientists of the developed world work. This dearth of research investment has meant that average yearly yields in South and Central America and in Africa are no more than 14 tons per hectare, even though field research shows that, with some improvements, cassava could grow four times as plentifully and feed many more people—both in areas where it is already grown and elsewhere.

Some interest is beginning to emerge in the developed world, however. Researchers at the Donald Danforth Plant Science Center in St. Louis are leading a project to insert genes—coming from other plant species or from bacteria—into cassava to increase its nutritional value and extend its shelf life [*see box above*].

The sequencing of the cassava genome, which is now in its first published draft, will likely boost the development of transgenic cassava. It will also aid conventional breeding programs through the technique of marker-assisted breeding, which relies on information gleaned from genetic analysis to guide the breeding of desired traits. Establishing a global network to coordinate efforts of all institutions that conduct research on cassava would ensure that the potential of this crop does not go to waste. ■

➡ MORE TO EXPLORE

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