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CIMMYT

Killing fields: poor farmers need new crop strains that can tolerate extremes such as drought. But the valuable skills of plant breeders (inset) are under threat.

A dying breed

Public-sector research into classical crop breeding is withering, supplanted by 'sexier' high-tech methods. But without breeders' expertise, molecular-genetic approaches might never bear fruit. Jonathan Knight reports.

Normally, at this time of year, agricultural scientists from around the world would be converging on the headquarters of the International Maize and Wheat Improvement Center, known as CIMMYT, in Texcoco, near Mexico City. They would then travel together to a desert field station near Ciudad Obregón in northwestern Mexico to study the current crop of experimental wheat cultivars, planted at the beginning of winter.

But not this year. For the first time in half a century, the research centre that helped to sow the seeds of the 'green revolution' of the 1960s and '70s has been forced to skip a cycle of wheat breeding trials, because of a lack of money. More than half of CIMMYT's fields in Obregón lie fallow, and the trainee plant breeders are staying at home.

CIMMYT is not alone. All over the world, conventional plant breeding has fallen on hard times, and is seen as the unfashionable older cousin of genetic engineering. "Plant breeding is getting dumped along the wayside for not being sexy enough," claims Greg Traxler, an agricultural economist at Auburn University in Alabama. Government funding of plant-breeding research has all but dried up in the United States and Europe, and the World Bank and donor nations have recently slashed their support for the Consultative Group on International Agricultural Research (CGIAR), the international research consortium of which CIMMYT is a part.

Meanwhile, a steady push by companies to claim exclusive commercial rights to new plant varieties has progressively tied the hands of publicly funded efforts at crop improvement. If this trend isn't halted, some experts claim, tomorrow's supercrops may end up like many of today's medicines: priced out of the reach of much of the developing world's growing population. "We are headed down the same path that public-sector vaccine and drug research went down a couple of decades ago," says Gary Toenniessen, director of food security at the Rockefeller Foundation in New York.

Sowing success

Classical breeders improve crops simply by crossing plants with desired traits, and selecting the best offspring over multiple generations. Sometimes they use chemical mutagens to disrupt crop genomes, in the hope that some of the resulting mutants will have useful new traits. Crosses may be as simple as letting two plants grow together, or they may require pollination by hand. And for crops such as wheat, one parent must first be emasculated to prevent self-pollination. In some ways, breeding is like accelerated, targeted evolution, and as long as test crops and seed banks are maintained, the possibilities can never be fully exhausted.

These methods, applied intensively at CIMMYT and the International Rice Research Institute (IRRI) near Manila in the Philippines, provided the impetus for the green revolution. Breeders produced dwarf varieties of wheat, maize and rice that were less likely to fall over in wind and rain, and which could carry larger seeds. Thanks to these varieties, farmers could use more fertilizer without risking losing their crops, and grain harvests in some areas have doubled or even trebled over the past three decades.

Central to CIMMYT's success in wheat was the practice of 'shuttle breeding', in which two seasons of plant selection could be completed in one year. Grain would be rushed from the fields in Ciudad Obregón after the harvest in April for summer planting in Toluca, near Mexico City.

This year's cancellation of the Obregón end of the shuttle was part of a 10% reduction in CIMMYT's programmes in the face of budget cuts, says the centre's director general, Masa Iwanaga. This was a result of the reduction in support for the CGIAR, which supports CIMMYT, IRRI and 14 other agricultural research centres around the world.

Whereas the CGIAR's funding crisis has

come to a head in the past couple of years, exacerbated by the global economic downturn, the world's academic plant-breeding labs have suffered steady attrition over a far longer period. Molecular genetics and transgenic technologies hold great promise for crop improvement, and have consumed a growing portion of the limited funding pie. University administrators have reinforced this trend, tending to replace retiring plant breeders with molecular geneticists who are more likely to produce high-profile journal articles.

Changes in the intellectual-property environment have also taken their toll. From the late 1960s onwards, developed nations introduced a legal framework of plant breeders' rights, giving new varieties and cultivars patent-like protection. The goal was to stimulate innovation in corporate labs, but the reforms also meant that public-sector breeders were no longer free to tinker with plants grown from commercial seed. "Plant-variety protection was the death knell for public breeding programmes," says Michael Gale, head of comparative genetics at the John Innes Centre in Norwich, Britain's leading public plant-science research institute.

Root of the problem

The figures reinforce Gale's view: until the 1960s, breeding for crop improvement was largely a public endeavour, but a survey of US plant scientists in the mid-1990s found more than twice as many breeders in the commercial sector than at universities and government agencies combined[1]. And although breeders' skills are still alive in the private sector, they are now working to subtly different ends. For seed companies and agribiotech firms, the top priority has been developing crops that can maximize profits from the intensive agricultural practices that are widely used in the developed world. Sadly, there is less money to be made in seeding a second green revolution for the world's poor.

In recent years, of course, the big news in the commercial and public sectors has been transgenic technology, rather than conventional breeding. Genetically modified (GM) crops that are resistant to the effects of broad-spectrum herbicides or that carry genes for insecticidal toxins have been widely planted across North America — but simultaneously shunned by European consumers, who are deeply suspicious of the technology. The welter of media coverage has obscured recent achievements in classical breeding, and although breeders generally view transgenics as a valuable tool, they stress that conventional breeding is far from obsolete.

In fact, for many GM crops, there is a comparable conventionally bred variety. The seed company Pioneer Hi-Bred, based in Des Moines, Iowa, for instance, produces a conventional, herbicide-resistant oilseed rape, or canola, that has similar advantages for weed control as its GM counterparts. And whereas the GM 'golden rice'[2], engineered to contain a gene that boosts the production of vitamin A by people who eat its grain, has attracted much publicity, conventional breeding is also being deployed to improve the nutritional value of this staple crop. IRRI has produced a cultivar of rice called IR68144 that bears grain rich in iron[3], and so could be used to combat anaemia. Even for crops such as the banana, which is unable to reproduce sexually without specialist human intervention, conventional breeding may still have a role to play (see "Bananas in the fertility clinic", below).

What's more, the GM crops developed so far generally involve only the addition of a single gene. Looking to the future, it's unclear whether complex traits, which are thought to involve multiple genes, will be amenable to manipulation through genetic engineering. "In the long term, you need heat tolerance, salt tolerance, greater yield and so on," says Paul Gepts, a crop geneticist at the University of California, Davis. "Some say you can do it with genetic engineering, but we just don't know how those systems work and how those genes interact." By contrast, practical experience has shown that conventional breeding can be used to improve a suite of subtle traits simultaneously.

All of this makes Donald Duvick, who was head of research at Pioneer Hi-Bred until his retirement in 1990, concerned about the future of crop improvement should the agribiotech giants lose their enthusiasm for transgenics. "I worry that the results will be so far in the future that industry will say 'we can't wait that long'," he says. If so, the depleted public-sector effort in plant breeding may be ill-equipped to take up the slack.

There are already hints that some companies are pulling back from long-term investments in high-tech crop improvement. Only last month, the Swiss-based multinational Syngenta closed its Torrey Mesa Research Institute near San Diego, which was a major force in crop genomics. And both Syngenta and its US rival DuPont, which owns Pioneer Hi-Bred, have recently withdrawn funding from the John Innes Centre. "The industry is in turmoil," says Gale.

Against this sombre background, can anything be done to safeguard future progress in crop improvement by reviving the science of plant breeding in the public sector? There is no easy answer, but some experts suggest that the future lies in boosting the power of conventional breeding by marrying it to genomic and other molecular-genetic techniques, while making a concerted effort to break with the proprietary approach to intellectual property that is currently blighting the field.

Bananas in the fertility clinic

Having shunned sex for thousands of years, bananas are in trouble. Those grown commercially are sterile mutants, propagated by replanting the suckers that sprout from existing trees. Lacking the genetic shuffling of sex, the single variety that dominates the export market is susceptible to any pest that evolves to evade its defences against disease.

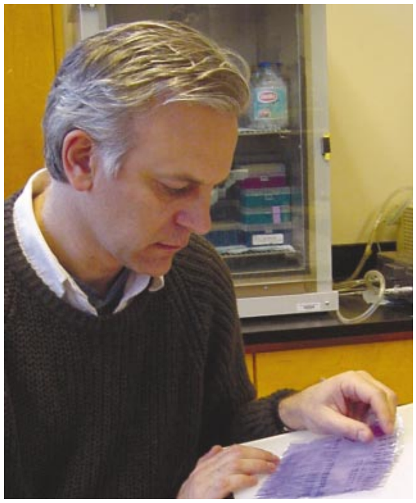
In the late 1990s, the emergence in Southeast Asia of a new strain of Panama disease, a wilt caused by the fungus *Fusarium oxysporum*, devasted commercial plantations. It has since spread to Australia and Africa, and if it lands in Latin America, where most export bananas are grown, farmers will need a new resistant variety.

Genetic manipulation seems the obvious answer — and researchers at the Catholic University of Leuven in Belgium have already produced several transgenic varieties that carry genes for antifungal proteins[5]. These will be field-tested for resistance to Panama disease over the next few years.

But even if they pass these tests, there is no guarantee that Europe's suspicious consumers will warm to the idea of transgenic bananas. So a conventional breeding effort is also under way. Breeders at the Honduran Agricultural Research Foundation in San Pedro Sula have found that it is just about possible to breed bananas, through careful hand pollination and sieving hundreds of tonnes of banana pulp to collect the few resulting seeds.

A. LOWE/REUTERS

One beacon of hope comes from a consortium of researchers at 12 institutions headed by Jorge Dubcovsky, a wheat molecular geneticist at the University of California, Davis. Its primary tool is 'marker assisted selection' (MAS). This technique, enthusiasts claim, could offer to plant breeding what the jet engine has brought to air travel. Traditionally, breeders have relied on visible traits to select improved varieties. For pest resistance, for example, that means examining mature plants in the field over successive generations to see which survive best in the face of attack by pests, before carrying out new crosses. MAS, however, relies on identifying marker DNA sequences that are inherited alongside a desired trait during the first few generations. Thereafter, plants that carry the trait can be picked out quickly by looking for the marker sequences, allowing multiple rounds of breeding to be run in quick succession.



Jorge Dubcovsky's genetic techniques aim to give traditional breeding a technological boost.

Superior breeding

MASwheat, as the consortium is known, aims to select for 23 separate traits in wheat, conferring resistance to fungi, viruses and insect pests. Its members also hope to breed the grain to produce bread and pasta of superior quality. Notably, the consortium is making all of its marker sequences and research protocols freely available. "If you go to our website, you have all the tools to do this anywhere in the world," Dubcovsky says.

For wheat, this admirably open approach was relatively easy to adopt, because it is one of the few crops to remain largely in public hands. Because wheat is self-pollinating, many farmers simply plant a portion of their harvest each year, safe in the knowledge that it will retain its desirable characteristics. Not surprisingly, this has restricted the interest of commercial seed producers, who don't see a robust market for their products.

Elsewhere, however, intellectual property is creating a heavy burden, with universities and other institutions facing barriers to the free exchange of seed, and restricted access to cutting-edge molecular technologies. "I wish it would all go away," says Kent McKenzie, director of the California Rice Experiment Station, which develops new varieties of the crop in its test fields at Biggs, north of Sacramento.

Extending the MASwheat consortium's approach to other crops may require public institutions to band together to end the practice of granting exclusive licences to individual companies each time they develop a powerful technology for crop improvement. To this end, Toenniessen has been meeting with representatives of ten 'land grant' universities — which form the backbone of agricultural research in the United States — to hammer out a plan. "If those in the public sector worked collectively, they could solve their problems," says Toenniessen. He hopes to pioneer the approach in speciality crops such as peanuts, broccoli, lettuce and tomatoes, in which the seed and agribiotech industry does not have strong commercial interests.

Richard Jefferson would go further. His Center for the Application of Molecular Biology to International Agriculture (CAMBIA) in Canberra, Australia, is trying to put cutting-edge technology for crop improvement directly in the hands of developing-world scientists and farmers, rather than leaving them to depend on the continued health of labs in rich countries. "The money is drying up and that is not going to change," he says. "We need to rethink the way crop improvement is done."

In part, Jefferson says, this will involve the transfer of transgenic technologies. But extending access to molecular-genetic enhancements to conventional breeding methods will also be crucial. Researchers at CAMBIA, for instance, have developed a DNA microarray that will boost MAS. In many crops, it is difficult to search for specific genetic markers, because very little of their DNA has actually been sequenced. But by immobilizing fragments of DNA from a variety of cultivars on a microarray and then seeing which of them bind to DNA sampled from individual plants, it is possible to look for the presence of genetic markers in these plants in the absence of any sequence information[4].

This technology has already been adopted by the International Center for Tropical Agriculture in Cali, Colombia, for cassava improvement. "It is extremely useful," says Joe Tohme, the centre's director of biotechnology. By making such techniques freely available, and allowing scientists anywhere in the world to tinker with and improve them at will, Jefferson hopes to speed progress. Essentially, he wants to create a crop-improvement counterpart to the 'open-source' software movement that has managed to flourish alongside the proprietary approach of giants such as Microsoft, which keep their programs' codes under wraps.

'Open-source molecular agronomy' is certainly a sexier label than conventional plant breeding. But will it have sufficient cachet to reverse the current decline in public-sector crop improvement? The food supply for future generations in the developing world could hinge on the answer. ■

Free for all: Richard Jefferson wants to put crop improvement within the reach of poor farmers.

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