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THE PLANT TECHNOLOGY TOOLKIT IN ACTION

New genetics across the globe

KEY THEMES

- Variety of appropriate technologies.
- Genetic modification: case studies.
- Guide to recombinant DNA technology.
- Drought stress: non-GM solutions.

Farmers need appropriate technologies

Any technology designed to increase productivity or add significant value must be appropriate to a farmer's particular circumstances: the environment, the labour available, the accessibility and affordability of the proposed technology, and so on. Many kinds of technologies can be appropriate:

- *Traditional* technologies are those that fit with local conditions and have been evolved over a long time by communities themselves – such as home gardens or locally developed methods of rainwater harvesting and irrigation.
- *Intermediate* technologies are those traditional ones that have been improved by coupling them with more modern techniques. Examples here include the treadle pump upgraded by modern engineering, and the practice of intercropping.
- *Conventional* technologies are those familiar in industrialised countries where knowledge of modern physics, chemistry and biology has been converted into products for use regionally or globally. Synthetic fertilisers and pesticides coupled with mechanisation are good examples.
- *New-platform* technologies are those that draw on innovations in biotechnology and nanoscience as well as information and communications technology (ICT), all of which have enormous potential in meeting the needs of both industrialised and developing countries. Genetically modified (GM) organisms and drought-tolerant or pest-resistant crop varieties that have been developed using new molecular selection and breeding techniques fall into this category.

Tricky choices

It is not always easy for a farmer to judge which among this extensive array of technologies is appropriate – even when they are accessible and affordable. High cost and the need for labour or concerns regarding environmental damage may make an apparently desirable technology impractical. A crop may well be selectively bred or engineered to resist pests and diseases, but does it also take up nutrients from the soil efficiently enough or reduce the need for water under local conditions? How will it respond to the stresses of global warming? Trade-offs may need to be made.

CASE STUDY Revolutionary new rice through marker-assisted selection

Rice growers in Asia have struggled for generations with extended periods of flooding that submerge their crop, stunting growth and impairing its viability. It is estimated that flooding affects more than 25 per cent of the world's rice-producing land – a proportion that may well rise as global warming increases the likelihood of flooding during the critical seedling stage, keeping the rice plants under water for several weeks on end.

Abdel Ismail/Dave Mackill/IRRI

In 2006 a team at the International Rice Research Institute (IRRI) in the Philippines took a big step forward in developing a new strain of submergence-tolerant rice using the relatively novel technology of marker-assisted selection (MAS). This enables the presence and structure of genes responsible for desirable traits to be selected at an early stage of seedling development at the level of their DNA sequences. The researchers at IRRI identified genetic markers associated with the ability to remain submerged, yet survive, for more than two weeks. This works through a mechanism that keeps the rice dormant during flooding, then allows it to grow as the water levels drop.

This became the key to a new rice – named Scuba – which is currently being bred using the new MAS technology. New submergence-tolerant varieties are being produced in Laos, Bangladesh and Thailand, and in India where more than 100,000 farmers have adopted one particularly promising variety.

The contribution of biotechnology

Biotechnology has been around for a long time, as long in fact as the centuries-old practices of brewing beer, fermenting wine and making bread. Today, though, the term has a much larger reach. We could define modern biotechnology as any technological intervention that uses biological systems, living organisms or their derivatives to make useful products and processes. At its heart lies our knowledge of the workings of DNA and RNA in determining the genetic basis of characteristics or traits (yield, drought tolerance, pest resistance and so on) in plants and animals. Undoubtedly, one of the best-known applications of these insights is the technique of recombinant DNA – often termed genetic engineering or genetic modification (GM) – in which genes from one organism are directly transferred into another. Box 3.1 describes briefly how it works.

BOX 3.1 A quick guide to recombinant DNA techniques

The basic process of locating and then transferring – recombining – a gene from one organism to another started to become practicable in the early 1980s; a decade later there was a dramatic surge in commercial applications of this revolutionary new technology. Human hormones were produced using bacteria as tiny growing factories, vaccines were engineered in yeasts, and genetically modified crops came on the scene.

Location and extraction

The first step is to locate the section of DNA – the sequence – of interest in the donor organism. This would be a sequence that determines – or codes for – a desirable characteristic or trait such as improved insect resistance or enhanced nutritional value, as with the biofortification of Golden Rice with vitamin A to prevent blindness. This sequence is then snipped out, or cleaved.

Transfer strategies, from bacteria to gene guns

Once extracted, the DNA then has to be relocated within the genome of its new host. One of the first and most successful techniques to be used for plants is a bacterial plasmid carrier or vector – small DNA elements in bacteria. The bacterium *Agrobacterium tumefaciens*, which causes crown gall disease, is commonly used as a vector because it naturally infects plants.

The desired gene sequence is inserted into a small segment of DNA, known as T-DNA (transfer DNA), from the bacterium, which in turn is incorporated into the host plant's DNA, sometimes through a method known as vacuum infiltration, in which plants are subjected to vacuum pressure to increase the contact between the bacterial vector and the plant's tissues.

In an alternative transfer process, the new fragment of DNA is coated onto the surface of gold or tungsten micro-particles which are injected into the host plant's cells with a gene gun, a process known as biolistics. Millions of cells are treated, and those in which the new gene has successfully integrated are selected using genetic markers to identify them. The selected cells are then cultured to grow into the new plant.

The method chosen depends on the target crop, with the *Agrobacterium* plasmid being the most routinely used transfer mechanism.

Advantages over conventional breeding

There are obvious advantages of speed and precision in recombinant DNA methods. And there are also huge potential economic pay-offs in terms of higher yields, greater tolerance to worsening conditions such as drought or increased salinity in the soil, and resistance to pests and pathogens. Fewer crops are lost and the farmer depends less on expensive chemicals such as fungicides and pesticides. Meanwhile the opportunity for no-till cultivation (no ploughing) is among the most significant benefits because it reduces fossil-fuel use as well as soil degradation. Lastly, there are qualitative benefits. Crops can be deliberately engineered to provide better nutrition, delivering higher levels of essential dietary ingredients or bearing valuable micronutrients where before they offered none.

CASE STUDY New Rices for Africa using tissue culture

The rising demand for rice in Africa is not being met by local production: each year 6 million tonnes have to be imported at a cost of more than US$ 1 billion. Biotechnology, in this case advanced tissue culture involving the growth of tissues or cells separately from the organism, is being deployed to meet this shortfall.

A Sierra Leone researcher – Monty Jones – based at the African Rice Centre, has used this technology to develop crosses between the African rice species *Oryza glaberrima* and the Asian species *Oryza sativa*, which typically has a yield five times that of its African counterpart.

The research was not all plain sailing. At first the technique simply did not work well, until collaboration with Chinese scientists provided a new coconut-oil-based culture method that delivered results.

Many new varieties – New Rices for Africa, which grow well in drought-prone upland conditions – have thus been generated. The new varieties also have good resistance to local pests and diseases and require low nutrient input. And they grow vigorously, crowding out weeds.

These new rices give the farmer many advantages, including the typical Asian characteristics of a full growth of grain that is ready to harvest 30–50 days earlier than the more local African crops. As a result, rice imports have been reduced. Uganda, for example, has halved such imports, while also boosting farmers' incomes by US$ 250 per hectare as they switch from maize to these new varieties of rice.

Yields up, imports down, and the farmers' returns on investment are enhanced: a triumph for tissue culture.

Compared to the kinds of innovations opened up by modern biotechnology, conventional breeding, whereby crop varieties with desirable traits are selected and crossed, can be quite slow and imprecise. Conventional breeding also often depends on the appearance of new, beneficial mutations, as was the case with quality protein (high-protein) maize, which only came into being after maize mutants with high levels of desirable amino acids were found quite serendipitously. Biotechnology takes away the waiting, making conventional breeding quicker and therefore cheaper, more targeted and more effective. At the same time, however, the procedure can be costlier and take longer to implement when GM is involved, because of the need to go through regulatory approval processes.

Not just biotech: other appropriate technologies have a role

For all its advantages, biotechnology is but one among a range of useful technologies. It would be wrong to think of it as a high-tech silver bullet for improving crop

production. The usefulness of other methods and approaches is clearly demonstrated by the ways in which farmers have tackled the age-old problem of drought – a threat made even more menacing as a result of global warming. The brief national accounts that follow show the range of these interventions in the face of severe water shortage.

Bangladesh

Large-scale irrigation systems are often not feasible in some of the least developed countries, where physical geography or low levels of wealth mean that smaller-scale solutions have to be found.

One such country is Bangladesh where, in the early 1980s, local people started to develop a new kind of pump to lift water from wells as an alternative to labour-intensive buckets and expensive oil- or petrol-powered pumps. They came up with a treadle pump: human powered, efficient, easy to use and to maintain, enabling

Globally, some 670,000 children die every year because of vitamin A deficiency, and another 350,000 go blind. Southeast Asia is the worst affected region, with 90 million children lacking this essential nutrient.

CASE STUDY Two generations of Golden Rice through genetic engineering

Rice is the basic dietary staple in Asia and parts of Sub-Saharan Africa, yet rice, in common with most cereals and other staples, is naturally deficient in essential proteins and other micronutrients. One huge lack is vitamin A, resulting in, among other things, a considerable burden of blindness and death in the human population, especially children. No fewer than 250 million children under five are estimated to be at risk from this deficiency. And more people die from vitamin A deficiency than from HIV/AIDS, tuberculosis and malaria combined.

At the Swiss Federal Institute of Technology, Ingo Potrykus along with Peter Beyer from the University of Freiburg used plant biotechnology to solve the problem. They concentrated on the gene responsible for synthesising beta-carotene, a natural precursor of vitamin A, which is present in both the daffodil and a bacterium. They extracted these genes and transferred them into rice where they began to activate the correct beta-carotene-producing biochemical pathways.

At first, beta-carotene levels in this first-generation Golden Rice (so-called for its distinctive colour) were not particularly high, but further research by scientists at Syngenta, the Swiss agrochemical company, uncovered another gene in maize which drove them far higher. Although it has been a decades-long, complicated and contentious story, this second-generation Golden Rice has already been developed into locally appropriate varieties in the Philippines and India, and these and other countries are expected to adopt it within a few years.

farmers to irrigate their fields either from natural water sources or from man-made wells. The current design enables an individual farmer to irrigate nearly a hectare of land under cultivation without the need for much more expensive pumps and fuel: an excellent example of intermediate technology.

The treadle pumps are also relatively cheap thanks to a combination of public subsidy and community involvement.

Thailand

For 200 years or more, farmers in the valleys of northern Thailand had managed their water supply through an arrangement of stone and timber dams linked to irrigation systems run by local representative bodies. Then in the 1960s and 1970s the Thai government began to construct larger-scale water diversion systems to increase year-round capacity. In doing so, they integrated the new developments with the existing, community-led management systems.

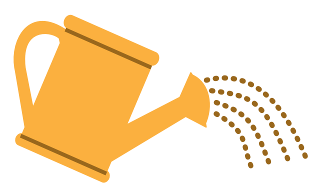
The technology was quite traditional, but the real benefits came from the traditional management structures, which ensured a sufficiently reliable water supply to enable farmers to plant a high-value, third-season crop in the same year.

South Africa

The common practice of tilling (ploughing) the soil before sowing seeds has some drawbacks. It makes soil more vulnerable to erosion and drought, harming its structure and increasing water loss. Farmers in southern Africa are avoiding these problems with another approach – conservation farming – an intermediate technique that protects soils and improves their fertility. It is also labour-saving.

Variants on traditional methods, clever, simple modifications to age-old practices, and updating conventional ideas can all contribute to increased food security.

In conservation farming, plant residues from the previous crop are left on the land, helping to minimise soil erosion and providing organic material, and there is no use of the plough. Instead, small hollows – or basins – are carefully dug to avoid turning over the earth, which keeps the soil organisms alive and retains precious moisture and nutrients. Two cupfuls of manure and a bottle top's measure of fertiliser are added. This considerably reduces the need for expensive chemical fertilisers. When it rains, instead of running over heavily tilled land and eroding the soil, the water seeps gently into it. Farmers then plant their new seeds in the basins where they germinate and grow. After harvesting, farmers cover the soil with the stems and leaves of the old crop, leave it fallow for a few months, then sow seed for the next crop in the same basins.



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With the *zai* system it has been possible to increase sorghum and millet yields by 80–170 per cent while also vastly improving the soil's long-term prospects for cultivation.

Despite the need for hoeing to control weeds, less labour is required overall and yields are high. In addition, this system tends to build up carbon in the soil, making the soil structure more stable, and the approach more sustainable than conventional agricultural methods.

Niger

For 50 years, farmers have been looking for ways to use expensive synthetic fertilisers – with their pollutant effects on water sources – more sparingly. The micro-dosing technique developed in Niger is one answer.

"Soda cap fertilisers" involve a soda bottle cap filled with a 6-gram mix of phosphorus and nitrogen fertiliser, which is poured into the hole before a seed is planted. This simple approach, using an everyday household item, has made an astonishing difference. Farmers are using between three and six times less fertiliser than their US and European counterparts, with no loss of efficiency. In fact, they are enjoying a 55–70 per cent increase in millet yield at far lower cost.

Burkina Faso

Even parched regions usually have a little available water. The challenge is to harvest these small amounts cheaply and efficiently. The response in Burkina Faso has involved a traditional technology, developed decades ago, known as the *zai* system. *Zais* or holes, 20–30 centimetres in diameter and 10–15 centimetres deep, are dug in rows across fields during the dry season and allowed to fill with leaves and sand as winds blow across the land. The farmers add manure to attract termites, which dig a complex network of tunnels beneath the *zais* and bring up nutrients from the deeper soils. When it rains, water collects in the holes where sorghum and millet seeds are sown. An arrangement of stone and earth ridges constructed around the fields' contours slows down any run-off. The result is that water capture is enhanced: the manure limits water loss through drainage, while the termites' porous tunnels allow deep infiltration.

With the *zai* system it has been possible to increase sorghum and millet yields by 80–170 per cent and, after five years or so, to upgrade the whole land surface for farming.

Appropriate technologies

The ingenuity of farmers in fighting drought stresses on their crops demonstrates that a high-tech, genetically sophisticated fix is not always necessary. But that is not to say that biotechnology cannot be of help. Improved seed varieties are still a vital basis for boosting yields and resisting pests and drought. The Water Efficient Maize for Africa initiative, for example, has benefited from knowledge of so-called chaperone genes, which help cells to repair damage caused by various stresses, including insufficient water. One such gene found in bacterial DNA and introduced by genetic engineering into maize DNA has shown excellent results in field trials, increasing maize yields by up to 15 per cent in plants subjected to drought, compared to those without the gene.

However, as we have seen, variants on traditional methods, clever simple modifications to age-old practices, and updating of conventional ideas can all play their part. There is a broad array of technologies out there, ancient and modern, from which today's food producers can draw.