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THE NECESSITY OF NEW TECHNOLOGIES
China's experience, yesterday and tomorrow

KEY THEMES

- Urgent productivity needs.
- New technologies, especially transgenics.
- Complex biosafety problems.
- Essential future role of biotechnology.

"Food is heaven for the people"

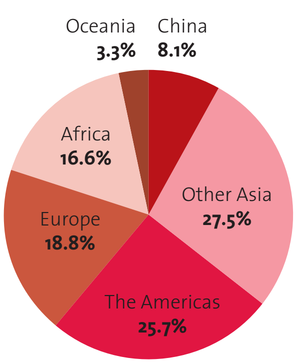
This ancient Chinese saying encapsulates the immense importance of an adequate food supply in ensuring stability and prosperity, sustainable development and peace. Food security has always been a core issue.

To maintain its food supplies, China has to cope with a perennially difficult tension between supply and demand. Its population, currently over 1.3 billion and rising at a rate of more than 5 million per year, puts huge pressure on agriculture. Yet Chinese arable land occupies a relatively small area, just 126 million hectares, which is being cut back all the time by rapid industrialisation, urbanisation and infrastructure development. How can China, which accounts for more than 20 per cent of the global population, feed its people from only around 8 per cent of the world's arable land?

Many problems, many challenges

Over the past 30 years a number of important changes have taken place. China has a long agricultural history: before the 1980s, agriculture involved more than 85 per cent of its workforce; today, in the wake of industrialisation and the wholesale relocation of rural populations to cities, it employs less than half of the population.

Figure 9.1 World arable and cropland by region



Total world arable and cropland 1.55 billion hectares

Source: FAOSTAT

Over the same period, alongside loss of labour and the progressive shortage of resources such as farmland and water, the use of pesticides and chemical fertilisers has risen sharply. Indeed, overuse has severely degraded many agricultural ecosystems – which are expected to come under yet more stress as a result of global climate change. This means that if China pursues traditional methods and practices, by 2030 it may well suffer a shortfall in food supplies of 120–170 million tonnes per annum: a severe threat to food security. The move to higher meat consumption as the economy continues to develop puts even greater demands on the supply of animal feed. In short, China has an urgent need to enhance crop productivity in an environmentally friendly, cost-effective and resource-efficient manner.

One solution is to use the existing genetic resources – the germplasm – within its crop plants more efficiently. Another is to draw on the new technologies to drive up productivity.

New germplasm and breeding technologies

Under the traditional style of farming, rice – one of China's most important staple foods – had poor levels of productivity, yielding less than 2.7 tonnes per hectare. For some decades, China has been making considerable efforts to drive this up by improving the crop.

The first milestone was the development of new semi-dwarf rice bred by creating hybrids of traditional semi-dwarf crops and high-yielding varieties. The newly bred varieties were shorter in height, resisted lodging (flattening down and so being more difficult or impossible to harvest) and produced more grain. They were widely cultivated from the early 1960s when many semi-dwarf crops were developed in different parts of the world – fruits of the Green Revolution. These new rice

CASE STUDY Transgenic cotton shows the way

China is one of the world's leading cotton producers, though it used to lose a significant proportion of the crop – worth tens of millions of dollars each year – to pests, especially cotton bollworm. Heavy pesticide use not only had highly adverse effects on agricultural ecosystems; it also led to the rapid development of resistance in the insect pests, making insecticides ineffective. The whole cotton industry was teetering on the edge.

Then, in 1991, came a research programme to develop transgenic insect-resistant cotton using artificially synthesised *Bacillus thuringiensis* (*Bt*) genes to confer resistance. By 1997 the relevant transgenic cotton technologies gained patents and a biosafety go-ahead for commercial production. The following year, about 5 per cent of China's total cotton-growing area was given over to the new transgenic varieties, which were then rapidly adopted across the major cotton-planting areas.

In 2003, China's locally produced insect-resistant transgenic cotton made up 50 per cent of its crop, rising to 75 per cent by 2011 – a total of 3.9 million hectares. Seven million smallholder farmers benefit from the new cotton, with their incomes markedly boosted and their use of chemical insecticides falling to less than 30 per cent of that in conventional crop fields. The environment is healthier, as are farm workers and their families who suffer fewer cases of spray-induced poisoning.

Another important beneficiary is the whole agricultural biotechnology enterprise. The practical and commercial success of *Bt* cotton has promoted research and development of other transgenic crops such as wheat, papaya and tomato, and vindicated the decision of researchers and governments to follow the transgenic route, when appropriate, for driving up agricultural efficiency.

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In the past, the production of hybrid rice strains was limited by rice's inherent propensity to self-pollinate. This was overcome when scientists developed a method which relies on various types of male sterility, thus preventing self-pollination.

crops exceeded yields of 4 tonnes per hectare and did much to overcome China's food security problems in the 1960s and 1970s.

A second milestone came at the end of the 1970s with improvements to breeding technology which made it possible to produce higher-yielding hybrids by relying on male plant sterility, along with the development of more semi-dwarf hybrid varieties that benefited from hybrid vigour. This is an increase in growth, survival and fertility resulting from crosses between genetically different parent crops.

The ensuing hybrid varieties showed a 20 per cent increase in grain yield compared with conventional semi-dwarf plants, which drove an expansion of the areas set aside for their cultivation from 5 million hectares in 1978 to around 16 million in 1990. This had profound effects on productivity. Although the total cultivated area of all rice varieties declined during 1975–2005, the total rice grain yield increased.

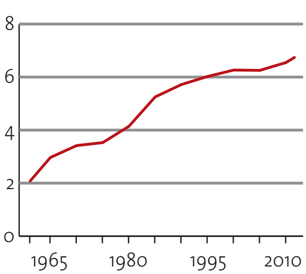
This use of elite genetic resources and new breeding techniques has paid off with crops other than rice – such as maize, wheat and rapeseed. Here, too, semi-dwarf varieties and hybrid vigour have led to huge increases in productivity.

Adopting these new varieties, however, has brought with it some drawbacks. Outputs are certainly high, but so too are inputs in the shape of chemical fertilisers and pesticides. This high-input/high-output system has led over time to degradation of the land, affecting its long-term productivity.

The need is clear for what has come to be called sustainable intensification – which focuses on achieving environmental sustainability through an ecosystem approach – aiming to maximise crop production through the careful management of biodiversity and ecosystem services. One strategy for overcoming limitations and meeting the need for sustainable intensification is to look to biotech solutions.

Figure 9.2 Rice yields in China, 1961–2012

Tonnes per hectare



Source: FAOSTAT

Transgenic biotechnology takes off

In the mid-1980s the Chinese government launched the first National High Technology Research and Development (R&D) Programme, which identified R&D in transgenic biotechnology and its application in agriculture and pharmaceuticals as an important aspect of the country's development strategy. National research projects focused specifically on transgenic crops and their commercial application. Since then, China has built up its capacity in the areas of whole genome sequencing, in which it is probably now the world leader; gene mapping and cloning; genetic transformation; transgenic breeding; biosafety assessment and management; and the commercialisation of transgenic products. To date, researchers have explored the potential of more than 52 plant species, including cotton, rice, maize, potato, tomato, wheat, rapeseed, soybeans and poplar tree. More than 100 transgenes have been used to create a large number of transgenic lines of crops with traits such as insect resistance, herbicide tolerance, improved grain quality and drought tolerance.

Poplars are one of China's most commonly planted species. A fast-growing tree used for veneers, plywood and timber, it is also used for reforesting areas that have suffered from intensive logging.

By March 2011, no fewer than 1,560 biosafety certificates had been issued for various crop species, with many more transgenic lines undergoing biosafety assessment. By the same date, a number of transgenic varieties were in commercial production (Table 9.1). Despite these advances, however, the commercial growing of transgenic crops in China has come under increasingly critical scrutiny. While the government strongly supports Chinese development of genetically modified (GM) varieties, there has been public concern about US control of the country's food supply through its biotech companies, as well as food scares.

Vital financial support

China's productive experience with cotton underscores the need for adequate funding for the substantial investment needed to deliver new technologies to the farmer in the field.

Direct funding came from central government through national research programmes sponsored by both the Ministry of Science and Technology and the Ministry of Agriculture. Provincial administrations, too, allocated funds, as did local

CASE STUDY A lesson in biosafety

As long ago as 1992, China cultivated, in Yunnan province, transgenic tobacco that was resistant to two viruses which cause the plant severe damage – tobacco mosaic virus and cucumber mosaic virus. The new varieties could have been extremely important both for farmers and for the export market, but cultivation was stopped by biosafety shortcomings.

At the time of the new tobacco's development, China lacked a well-established national biosafety regulation and assessment system, so was unable to carry out the proper regulatory procedures; it certainly could not export the new products internationally. So some excellent, front-end research and development had to come to a close.

Table 9.1 Genetically modified species commercialised or having biosafety certificates in China

Crop	Species	Year of commercialisation or biosafety certificate	Trait	Status of application
Cotton	*Gossypium hirsutum*	1997	Insect resistance	3.9 million hectares
Petunia	*Petunia hybrida*	1997	Flower colour change	Small-scale
Tomato	*Lycopersicon esculentum*	1998, 2000	Virus resistance, storage endurance	Small-scale
Sweet pepper	*Capsicum annuum*	1998	Virus resistance	Small-scale
Poplar tree	*Populus tremula*	2005	Insect resistance	Small-scale
Papaya	*Carica papaya*	2006	Virus resistance	About 10,000 hectares
Rice	*Oryza sativa*	2009	Insect resistance	Biosafety certification
Maize	*Zea mays*	2009	Phytase for improved feedstuff	Biosafety certification

Source: Bennett and Jennings, 2013

research institutes and universities. Commercial companies and non-governmental organisations also played their part in the overall investment.

Biosafety: a complex problem

In China, as elsewhere, the extensive cultivation of transgenic crops has aroused huge concerns over biosafety – a central topic for debate which simply cannot be avoided if the new technologies are to be developed and applied. Following biosafety assessment, any GM crop must, by law, receive a biosafety certificate or deregulation permit before it can be commercially cultivated.

Earlier experience with transgenic tobacco in China shows how essential it is to deal with biosafety matters properly if biotechnology producers are to succeed in the marketplace (see Case study).

Biosafety in the context of GM and other innovatory technologies is a complicated business which needs consideration at every stage: threats to human and environmental health can exist in the research laboratory as well as in the fields or supermarkets. There are several biosafety concerns:

- potential health risks to humans, livestock and wild species from consuming GM products;
- environmental and ecological risks from extensive cultivation of the new crops in monocultures;
- useful and informative labelling of commercial products and the detection of transgene-derived protein if they are not so labelled;
- ethical and socio-economic concerns;

- public perception/acceptance of these products;
- regulatory procedures for GM products;
- risk assessment systems governing commercial release and cultivation.

One can see many of these considerations in play in the case of gene flow – the flow of genes from cultivated to wild relatives or between crops – a topic which has aroused much debate, even worldwide, both within the scientific community and among the public at large.

China's biosafety response

In 1993 the Ministry of Science and Technology issued an important legal document – *Safety Administration Regulation on Genetic Engineering* – to serve as a

BOX 9.1 What's the worry over transgenes?

The central concern turns on the potential ecological impacts of transgenes flowing by cross-pollination from genetically modified (GM) crops to the equivalent non-GM crop or wild species, transporting engineered genes to new hosts where they could have damaging effects. A gene coding for herbicide tolerance, for example, might make its way into the related weed population and create superweeds that frustrate a farmer's attempts to control them. Other objections are that transgenes flowing from GM crops might limit biodiversity or even cause the extinction of local wild plant populations.

In certain cases, crops may interact with related wild plants to form crop-weed complexes – for example between cultivated sugar beet and wild sea beet. These weed populations can act as reservoirs of foreign genes, potentially including genes introduced by genetic engineering. And they can also act as bridges, allowing gene flow between crops and wild species that are usually unable to interbreed.

Then there is a health worry: that transgenes coding for antibiotic resistance might flow into bacteria, causing new antibiotic resistance problems for humans. We all have anything up to a kilo of bacteria in our intestines, which for the most part already contain antibiotic-resistance genes, due in part to excessive or inappropriate use of antibiotics by people and the medical profession.

The questions raised by transgenes have influenced decision makers considering the commercial application of GM crops as well as the general public and consumers. And that, in turn, has caused difficulty for scientific researchers who have had to think hard about how much data is needed to prove whether or not GM crops are safe for consumption or to be released into the environment.

The development and cultivation of virus-resistant transgenic papaya – in which the plant is "immunised" with a gene from the virus – has largely solved the problem of papaya ringspot virus, which used to cause major setbacks for papaya growers.

framework on all biosafety matters, ranging from research and experimentation to commercialisation, labelling, import and export. Further regulatory documents have followed since then, as has the establishment of a top-level panel of experts forming the National Biosafety Committee.

Today, China has in place a rigorous procedure for taking any GM crop proposal through biosafety assessment and on to commercial exploitation. To receive a biosafety certificate, a novel crop has to go through a five-step process: confined laboratory safety investigation; restricted field tests; enlarged field testing; production-scale tests over more than 2 hectares; and finally safety certificate application. This is essentially the same procedure as for any crop that is approved for market in the developed world.

Future prospects for new technologies

China has come to a decisive conclusion to ensure its future food security. It believes that, in order to feed its swelling population in an environmentally friendly, sustainable manner, it needs to apply new technologies in general and transgenic crop technologies in particular. These are powerful tools that cannot be ignored.

Biotechnology for food production is firmly on the government's agenda, inspired by the huge success of transgenic cotton, which has rescued China's cotton industry, and other GM crops. Many R&D projects are now under way, particularly ones following the transgenic route.

Genetic modification and biotechnology have already significantly improved the efficiency of the country's agriculture: reducing pesticide use, improving herbicide resistance and thereby labour practices, and increasing yields. They have become – and will continue to be – intrinsic to China's food supply and security in the future.