

Genetic Modification: Overview of Benefits and Risks

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1. Introduction

Genetic modification involves the transfer of specific genes to new host organisms, so that these hosts are able to do new things not possible with just their own set of genes. It has the potential to revolutionise both the medical/health and food/agriculture industries, and so change the lives of billions of people. Associated with both medical and agricultural applications, however, are growing concerns over the potential environmental and health costs. Institutional and policy mechanisms already lag behind scientists' and industry's capacity to find new uses for the technologies. Ethical issues that require considered and extensive public consideration are in danger of being lost amid the technology rush.

Biotechnology involves making molecular changes to living or almost-living things. It has a long history, dating back to the development four thousand years ago by Egyptians and Sumerians of fermentation, bread-making, brewing and cheese making. Modern biotechnology or genetic modification, by contrast, is the name given to the technology that transfers DNA from one organism to another, so allowing the recipient to express traits or characteristics normally associated just with the donor. As these transfers or mixes do not occur in nature, the scope for genetic modification is far greater than in conventional animal or plant breeding.


2. Progress in the Early Years

The biotechnology industry is now the fastest growing sector associated with both the health and the food systems. There are some 1500-2000 biotechnology companies in the USA, and a further 700 in Europe, the majority of which are concerned with the production of new drugs and other medical applications. In the food and farming sector, six international conglomerates now dominate the market: Monsanto, Novartis, AgrEvo, Dupont, Zeneca and Dow. They are said to have already invested \$8 billion in technology development; Monsanto alone spent \$730 million on biotechnology research during 1997. Several have come to dominate the seed market too - ten companies now account for 30% of the global \$23 billion commercial seed trade, including Pioneer Hi-Bred (\$1.7 bn), Monsanto (\$1.32 bn) and Novartis (\$0.93 bn).

The expansion in the cultivation of GM (genetically modified) crops has been very rapid in recent years. In 1994, there were no GM crops grown commercially on farms anywhere in the world. By 1998, some 29 million hectares of GM crops were cultivated in the USA, Australia, Argentina, Canada and Mexico, up from 12 million ha in 1997. In 1998, GM crops were sown on a quarter of all cotton area in the USA, 43% of soya (up from 14% in 1997) and 20% of maize (up from 1% from 1996). In China, 650,000 farmers planted Monsanto's Bollgard cotton in 1998, rising to about 1 million in 1999.


The first genetically engineered products eaten by humans were cheese and tomatoes. GM bacteria were first used to produce an alternative enzyme, chymosin, to calf rennet so as to make vegetarian cheese. Then in 1995, tomatoes with their softening gene 'switched-off', allowing them to ripen on the vine until they reach full flavour and colour without rotting, were introduced to the market as tomato paste.

But the greatest growth has been in crops containing one of two traits:

 herbicide tolerance, mainly in soya, oil seed rape (canola) and sugar beet,

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which allows the application of broad-spectrum herbicides to the standing crop, without causing it damage but killing all the weeds;

 insect resistance through *Bacillus thuringiensis* (*Bt*) expression, mainly in maize and cotton, which means that the *Bt* insecticidal toxin is expressed by all cells of the plant, so killing herbivorous pests and theoretically reducing the need to apply conventional pesticides.

In 1998, 71% of the world's commercial GM crops were herbicide-tolerant, 28% were *Bt* crops, and 1% a combination of both (not counting virus-resistant crops in China).

In the research pipeline and awaiting commercial approvals are a wide range of 2nd generation GM crops, including potatoes resistant to Colorado beetle; resistance to cucumber mosaic virus in cucumber, lettuce, tomato, pepper and other horticultural crops; fruit trees and strawberries protected from the codling moth and vine weevil; rice resistant to rice yellow mottle virus and tungro disease; bananas resistant to nematodes; viral-resistant papaya able to resist ringspot; and sweet potato plants able to resist the feathery mottle virus (DFID, 1998; Science Museum, 1999).


To top of report

3. Divided Camps and Different Technologies

Only a few years after the development of the first GM crops for agriculture, it is already clear that opinion on utility and risk is sharply divided. Some argue that GMs are necessary, entirely safe and essential for world progress; others state they are not needed, are inherently unsafe, and hold great risks. The first believes that media manipulation and public scare-mongering are limiting useful technologies; the second that scientists, private companies and regulators are understating hazards for the sake of economic returns.

Neither view is entirely correct, for one simple reason. Genetically-modified organisms are not a single, homogenous technology. Each poses different potential benefits for different stakeholders, each poses different environmental and health risks. This is an important fact that has received little attention (see, for example, House of Lords Select Committee, 1998; Nuffield Council on BioEthics, 1999; British Medical Association, 1999; The Royal Society, 1999). It is important, therefore, to distinguish between different types or generations of GM technologies (Table 1). It is clear that the first generation technologies have tended to provide substantial private benefits for the companies producing them - herbicide-tolerant soya, for example, locks farmers into buying the herbicide produced by the company marketing the GM seed (eg Monsanto, Roundup® or glyphosate, and Roundup Ready soya). *Bt* maize and cotton permits reduced applications of insecticides, so saving farmers money, but the extra cost of the seeds means that companies capture the entire margin. Both could still deliver substantial environmental benefits, but as discussed in the next section, these have begun to unravel during 1998-99.

Table 1. Details of first three generations of GM technologies and key characteristics

Generation of technology	Technologies and characteristics
<i>First Generation</i> In commercial use during late 1990s	 Herbicide-tolerance

	<ul style="list-style-type: none"> 🌱 Rapid ripening tomatoes 🌱 Bacteria in containment systems for production of cheese and washing powder enzymes 🌱 Pre-coloured flowers and cotton (eg blue cotton, violet and black carnations)
<p><i>Second Generation</i> Developed by late 1990s, but not yet commercially released</p>	<ul style="list-style-type: none"> 🌱 Viral resistance in rice (eg to rice yellow mottle virus), cassava, papaya, sweet potatoes, pepper 🌱 Nematode resistance in various cereal and other (eg banana) crops 🌱 Terminator gene technology (suicide seeds) 🌱 Verminator-spray package (eg dicloramid to be used as a crop spray to switch on/off rat gene (hence verminator) that uncouples key proteins) 🌱 Frost tolerance (gene from the Arctic flounder fish into strawberry, sugar beet, tomato, and potato) 🌱 Pharming – crops and animals ‘pharmed’ to produce pharmaceuticals (eg sheep and pigs modified to produce human proteins in their milk, such as insulin, interferon, and the human blood clotting protein factor 8; rice modified to produce alpha-antitrypsin, a protein valuable for treating liver disease and haemorrhages).
<p><i>Third Generation</i> Research underway</p>	<ul style="list-style-type: none"> 🌱 Stress tolerance in cereals: eg thermo-tolerance in pearl millet to overcome failure of seedling establishment; salt and heavy metal tolerance; drought-resistance (genes that control root growth) 🌱 Physiological modifications of crops and trees: to increase plant efficiency of resource use (nutrients, water, light) through faster growth, longer growing seasons, modification of plant hormones to affect grain filling, or delaying of ageing in leaves to prolong carbohydrate production 🌱 Apomictic crops, so that hybrid seed can be reused 🌱 Nutraceuticals - crops boosted with vitamins or other valued minerals 🌱 Vaccine crops - crops (banana and potato) containing genetic material from harmful pathogens that work like vaccines when eaten 🌱 Designer crops - plants modified to produce oils or plastics 🌱 Development of new marker genes to replace antibiotics (eg fluorescent proteins) 🌱 Rapid expansion of ‘pharming’ applications

An example of a 2nd generation technology (those developed but not yet released) is the so-called ‘Terminator’ technology (as dubbed by campaigners) or Technology Protection System (as named by companies). This involves the insertion of various gene switching mechanisms that ensure that any seed saved after harvest will not germinate. As most farmers in developing countries and a surprisingly large number in industrialised countries (20-30% of US soya farmers reuse seed, and large numbers of wheat farmers only return to the market once

every 4-5 years) save their seed, this technology transfers power from farmers to companies. It has not surprisingly come in for substantial criticism. The 3rd generation GMs, by contrast, are clearly more multi-functional and public-good oriented, though clearly not without risk. If crops are developed with thermo-tolerance, drought, salt or heavy-metal tolerance, it could make a substantial difference for farmers on problem soils or in difficult climates. Physiological modifications of rice and wheat could mean faster growth with existing nutrient, light and water resources, and a longer growing season, allowing farmers to benefit without getting locked into new corporate dependencies.

A considerable breakthrough would occur with the transfer of apomictic traits (the production of exact clones of the mother plant through asexual reproduction) into cereals. Research underway in Mexico by CIMMYT is seeking to transfer apomixis from a grassy relative of maize, *Tripsacum*, to maize itself, which would allow hybrid seeds (higher yielding but infertile) to be saved by farmers for subsequent seasons. This technology is the exact opposite of the terminator technology. Further away is the possibility of developing nitrogen-fixation in cereals, which would offer the possibility of increasing cereal yields without inorganic N fertilizers.

[Back to Divided Camps and Different Technologies](#)

[To top of report](#)

4. The Environmental and Health Risks of GM Crops

There are a range of core environmental and health risks posed by GM crops (see, for example, Rissler and Melon, 1996; Altieri, 1998; Pretty, 1998a; House of Lords, 1998; Royal Society, 1999; BMA, 1999):

Environmental risks

- Genetic pollution and horizontal gene flow to wild or weedy relatives of crops;
- Emergence of resistance amongst insect, nematode, or fungal pests;
- Recombination of viruses or bacteria to produce pathogenic strains ('super-viruses'), and their possible escape into natural ecosystems;
- Sequestration of toxins by herbivores (eg Bt) into somatic tissue, causing secondary effects on predators;
- Disruption of soil ecology following breakdown of crop tissue and release of toxin (eg Bt in first generation GMs, but with patents already secured on genes for toxins from scorpion, cone snail, funnel spider and wasp).

Health risks from GM food consumption

- Allergenic and immune system reactions to new substances contained in foods (note that it is important to distinguish between consumption of food products potentially containing GM DNA, and food products that are identical to those from conventional crops, such as refined sugar);
- Incorporation of antibiotic-resistance marker genes from GM foods into bacteria.

A framework for judging risks involves setting the environmental and health benefits on one side of the balance sheet and the risks on the other. The problem that regulators face is that too little is known about either of these. The technologies are young, and the risk research continues to identify new areas for concern. What appears to be a simple equation inevitably becomes steadily more complex over time.

Take *Bt* maize for example. On the plus side, it should lead to reduced use of insecticides (good for the environment and health). On the risk side is concern about toxin-sequestration and direct effects on beneficial insects, such as butterflies, lacewings and ladybirds, and disruption of soil ecology (Altieri, 1998; Crecchio and Stotzky, 1998; Losey et al, 1999).

When empirical research discovers a reduced benefit or increased risk, then the balance can change markedly. Until late 1998, for example, companies marketing *Bt* maize had argued that pest-resistance to *Bt* would not be a problem. But in September 1998, Novartis issued new rules to its growers, stating that 40% of their farms would have to be planted to non-GM crops so as to provide pest refuges (the company now calls this a strategy for 'Integrated Resistance Management'). Resistance had emerged on such a scale that the GM technology was no longer effective on its own.

The question of whether there has been a bonus of reduced insecticide use is now contested. Novartis are convinced. But the USDA's own National Agricultural Statistics Service (1999) has recorded that the majority of maize insecticide has been applied at pre-emergence stage for control of corn rootworms, cutworms and other soil insects: "*there has been little change in insecticide use, despite the planting of millions of acres of Bt corn in recent years*". Data submitted to the US Environmental Protection Agency by the National Corn Growers Association (NCGA, 1999) in April 1999 showed that the proportion of US maize crop sprayed against corn borers (the target of *Bt* maize) increased by 45% in the first two years of *Bt* maize use (1996-97).

Roundup Ready oil seed rape and soya are other examples. On the plus side, they should lead to reduced herbicide use - again good for the environment. But again, it is what happens in the field that determines the real risks. Complexities of weed agronomy mean that herbicide use on these GM crops appears to be on the increase in the USA. Farmers are faced with a choice: i) let the weeds grow to a size that allows a complete kill on spraying, but which means yields will have suffered owing to competition from the weeds; ii) use a pre-emergence herbicide plus the broad-spectrum product; or iii) apply the broad-spectrum product at least twice. It is increasingly reported that farmers are resorting to both the latter two options - meaning that these GM crops are actually leading to increased herbicide use.

On the risk side, dispersed pollen (from rape only) travelling considerably further than originally thought could lead to gene flow to wild relatives (BCPC, 1999), producing herbicide-tolerant superweeds, and the complete weed-kill achieved by broad-spectrum herbicides leads to the loss of food sources for both insects and birds (ACRE, 1998; Royal Society, 1999).

Several other studies have found yield and agro-chemical use dividends hard to come by, with GM cotton in Arkansas needing more growth regulator, having to be picked twice (so raising costs), and yielding 25kg/ha less than conventional cotton (Myers, 1999); GM soya was found to have lower yields at 17 sites in 9 states during 1999 (University of Wisconsin study; and elsewhere yields of GM soya were to be lower and herbicide use higher (Owen, 1997). These studies may not be representative, but they do indicate that all is not well with these specific technologies.

A set of key questions to help inform the debate about GM crop and food risks have been recently developed (Pretty, 1999). If the answers are predominantly yes, there is need for less caution. If they are mainly no, then there is almost certainly a case to be made for more research and greater understanding before commercial releases.

It is clear that these questions need regular revisiting, as new evidence for benefits and risks is constantly emerging. The problem is that regulators and policy makers tend to lag behind the science. In a recent editorial, *The Lancet* stated that it was "*astounded that the US Food and Drug Administration has not changed their stance on GM food adopted in 1992*" (*The Lancet*, 1999).

1. Does the GM process only involve gene transfers within the same or related species?

If yes - Gene sequence more likely to be stable and predictable

If no - Need for considerable research and testing to ensure no genetic instabilities and/or pleiotropic effects

2. Is the GM process fully contained? (ie does the technology involve no release to the environment of GMOs?)

If yes - Little to no environmental risks eg GM bacteria producing insulin and biological active enzymes for washing powders; gene therapy for medicine

If no - Genetic pollution and horizontal gene transfer become a risk

3. If GM crops are released to the environment, will they affect only target organisms as predicted?

If yes - Risks can be contained within limits in ecosystems

If no - Risks of disruption of ecosystems greater, eg via sequestration of toxins by herbivores, direct toxic effects on beneficial insects

4. Is the likelihood of food toxicity or antibiotic resistance effects in GM foods as low as or lower than for other foodstuffs?

If yes - Food products likely to be safe especially if product consumed is identical (eg refined sugar)

If no - Food products need thorough testing before consents/release

5. Is the GM product fundamentally for the public good? Will it be distributed through public extension systems?

If yes - Technology more likely to be accessible to poorer farmers and countries, eg apomictic traits (for seed saving), N-fixation in cereals

If no - Main aim is to sell more company products (eg seeds, agro-chemicals), and use of terminator technology to lock in farmers

6. Are claims for environmental benefits arising from GM use on the farm supported by practice?

If yes - GM technologies lead to environmental benefits, particularly if substitute for conventional practices

If no - GM technologies contextualised by details of farm practice, and so need further research (eg herbicide tolerant crops leading to greater herbicide use)

[Back to The Environmental and Health Risks of GM Crops](#)

[To top of report](#)

5. GMOs and Feeding the World

An important aspect of the sustainable development question (not least because the spectre of famine has been repeatedly raised by certain stakeholders as a way to gain greater support for GM technologies as a whole) is: can GM crops help to feed the world?

Some say emphatically yes. One of the biggest advocates of the 'saving the world' line is Monsanto, whose 1998 public relations campaign, 'Let the Harvest Begin' (sic), stated that Europeans should stop being selfish in refusing to accept GM crops and foods, and that "*agricultural biotechnology will play a major role in realising the hope we all share. Accepting this science can make a dramatic difference to millions of lives*".

But where does this stand in the myth to truth spectrum? Are GMs necessary for feeding the world? If so, which ones will make the difference? It is clear that as we approach the new millennium, the world faces a massive food security and production challenge. Although the world population currently stands at 5.9 billion people, the UN Population Fund predicts increases to 8.4 billion by 2050, by which time 84% of the world's population will be in those countries that currently make up the 'developing' world.

The prospects do not appear to look good. Most commentators agree that food production will have to increase, and that this will have to come from existing farmland. Many predictions are gloomy, indicating that the gap between demand and production will grow. Past approaches to agricultural development have not

been sufficiently successful in many parts of the world. In Africa, for example, per capita food production has fallen by about 20% since the mid-1960s. This much is agreed, but what we do about it is highly contested. Feeding the world is not a simple problem. We actually produce enough food in the world to feed everyone with a nutritious and adequate diet now – some 354 kg of cereal per person per year. But today there are some 828 million hungry people. An important factor is poverty. People are hungry because they are poor. They simply do not have the money to buy the food they need. Poor farmers (and poor countries) cannot afford expensive ‘modern’ technologies that could theoretically increase their yields. What they need are readily available and cheap means to improve their farms and livelihoods.

So a cereal crop engineered to have bacteria on the roots to fix free nitrogen from the air, or another with apomixis, would be a tremendous benefit for poor farmers. But unless this technology is cheap or freely available, it seems very unlikely that the people who need it most would ever have access. If it is the terminator-technology that predominates, then can this really benefit the two billion people in developing countries currently relying on largely ‘pre-modern’ agricultural systems?

Food insecurity is not a simple question of a lack of a new technology. More than 800 million people are hungry because they are poor – and poor people will not be in the market for expensive new technologies, whether genetically-engineered or not. And if they cannot afford them, no amount of ‘modern’ technology developed by companies seeking to make a financial return will make any difference for them. They will have to find cheap solutions based on existing resources.

Sustainable agriculture is now a viable alternative (Pretty, 1995, 1998b; Altieri, 1995; Conway, 1997). It seeks to make the best use of nature’s goods and services whilst not damaging the environment. It does this by integrating natural processes such as nutrient cycling, nitrogen fixation, soil regeneration and natural enemies of pests into food production processes. It minimises the use of non-renewable inputs (pesticides and fertilizers) that damage the environment or harm the health of farmers and consumers. It makes better use of the knowledge and skills of farmers, so improving their self-reliance and capacities. Sustainable agriculture is also multi-functional – it produces food and other goods for farm families and markets, but it also contributes to a range of public goods, such as clean water, wildlife, carbon sequestration in soils, flood protection, and landscape quality. Many of these non-food functions cannot be produced by other economic sectors.

Remarkably, the best evidence of ‘success’ comes from those very countries of Africa, Asia and Latin America that some say are most in need of GM technologies. Where whole communities have been involved in the complete redesign of farming, the sustainability dividend is very large. Regenerative technologies and practices can be hugely beneficial for both farmers and rural environments. The University of Essex is engaged in evaluating and documenting 300-500 sustainable agriculture projects from around the world, so as to inform a judgement on how the world can best be fed in the next century. It is already clear that sustainable agriculture can lead to substantial yield increases – probably sufficient to feed developing country populations. A selection of initial findings is as follows:

Africa

- 45 projects in 17 countries with 730,000 farm households, all with yield increases of 50-100%;
- 100,000 farmers in Benin using *mucuna* bean as a green manure and cover crop with maize to suppress weeds and fix nitrogen, all of whom have

increased crops yields;

- 100,000 farmers in Niger and Burkina Faso using water harvesting and organic methods to restore drylands, leading to reversal of household food deficits to surpluses.

Latin America:

- 9 million ha in southern Brazil under conservation farming, low to zero-tillage, green manures and cover crops, all with substantial yield increases and reduced agro-chemical use;
- 45,000 farmers in Guatemala and Honduras using regenerative technologies to triple maize yields to some 2-2.5 tonnes/ha, leading to local economic growth that has in turn encouraged re-migration back from the cities;
- 100,000 small coffee farmers in Mexico have adopted organic production methods, and yet increased yields by 50%;

Asia

- a million wetland rice farmers in Bangladesh, China, India, Indonesia, Malaysia, Philippines, Sri Lanka, Thailand and Vietnam using integrated pest management methods learned in group-based farmer-field schools have cut pesticide use to 10-25% of former levels whilst still increasing yields by about 10%;
- 300,000 farmers in dryland India using water and soil management technologies have tripled sorghum and millet yields to some 2-2.5 tonnes/hectare;

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