Sustaining the Food supply of A Developing World: Genetically Modified Crops Enter Their Second Decade,

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> How can we ensure that an ever-green revolution movement based on genetic and digital technologies is characterized by social and gender inclusiveness? The answer to this question was given by Mahatma Gandhi more than 70 years ago when he said, “Recall the face of the poorest and the weakest person you have seen, and ask yourself, if the steps you contemplate are going to be of any use to him.” An *antyodaya* approach—that is, development based on attention to the poorest people—to bridging the digital, genetic and gender divides, adopted in our biovillages in India, has proven very effective in including the excluded in technological and skill empowerment.
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> M. S. Swaminathan
> Recipient of the 1987 World Food Prize
> *in*
> HUMAN DEVELOPMENT REPORT 2001, Making new technologies work for human development,United Nations Development, Programme/Oxford University Press, 2001

Introduction

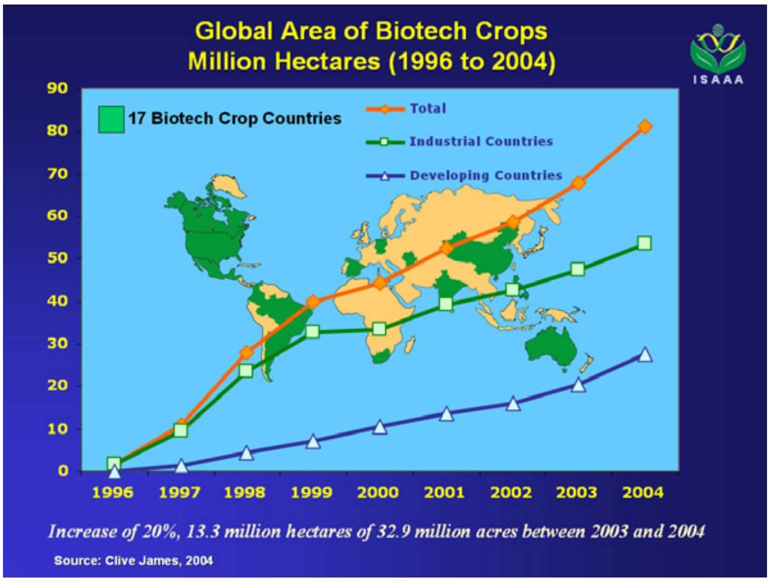
Crops generated using laboratory methods which directly manipulate DNA are now commonly called genetically manipulated or GM crops (alternatively trems are transgenic crops, or biotech crops). The year 2006 will mark the 10th anniversary of entry of these crop varieties into the world's agricultural trade.

This controversial first decade of GM use started with rapid adoption of GM crops by the major agricultural commodity exporting countries. The early GM crop users were primarily the farmers operating large scale commercial farms of North America, South America, Australia, and South Africa. These farmers were already the leading users of advanced agricultural technologies to produce food, feeds and fibres at low cost for trade in competitive world markets.

During this first decade, rapid initial expansion of farm are sown with GM crop occurred despite much controversy about the use of modern genetic techniques in food production, and this healthy and robust controversy about pros and cons of transgenic crops is expected to continue.

In this current paper focuses on the events expected to occur in the second decade of GM crops – the years leading up to 2016. This is a period in which fundamental limitations of agricultural resources in developing countries – such as limited arable land area in China, limited land and water supply in India – will need to be reconciled with substantially increased food demand from more prosperous and larger populations.

A change was already occurring towards the end of the first GM crop decade in the global character of GM crop farming, as shown in Figure 1. In this figure it can be seen that during the years 2000-2004, crop area sown with biotech crops in the developing countries started to catch up with the area sown in industrial countries.


Global Area of Biotech Crops
Million Hectares (1996 to 2004)

Increase of 20%, 13.3 million hectares of 32.9 million acres between 2003 and 2004

Source: Clive James, 2004

Figure 1. Graph of growth in global crop area devoted to GM crops, showing the rising contribution from developing countries (Clive James, ISAAA).

In the years following 2006 it can be predicted that transgenic-crop based agriculture will substantially affect economics and human welfare in the developing countries (principally China, India, Argentina, Brazil and South Africa) and change the lives of their smaller landholders. In developing counties during 2004, growth of GM crop area was three-times stronger than it was in industrial countries and 90% of farmers using GM crops were in the developing countries. In 2004, GM crop area sown in developing countries was 34% of the total 81 million hectares of GM crops sown (ISAAA, www.isaaa.org)

It is in developing countries that food costs constitute a much larger fraction of family income than in the rich countries with their relatively cheap food. In developing counties too, more than in rich countries, agriculture usually forms the backbone of

the economy, but to meet demand for food, feed, and fibre, land and water resources are often stretched to the limit. Difficulties in managing crop losses to pests, and crop spoilage caused by microbes are more serious in developing counties. For all these these reasons, it seems likely that improvements in farm productivity and avoidance of health and environmental costs of agriculture being provided by transgenic crops to developing nations are likely to provide more compelling arguments for the wider acceptance of GM crops than their current economic successes in developed countries.
Recent good news from the developing world, given in detail later, includes:
Dramatic improvements to Indian cotton crop output sparked by the use of transgenic cotton varieties that contain a protein that deters insect pests.
Better health and less pesticide use by Chinese rice farmers who use rice varieties that are protected against insect damage by a GM trait. These new rice varieties enable Chinese farmers to also get more rice from the same land.
Good experiences of South African small holder farmers in growing white maize as their staple food, who are enthusiastic about being saved much hard labour weeding in the hot sun by sowing transgenic maize seed that is herbicide tolerant.

Use of breeding methods in agriculture.

To help understand the importance of modern genetic modification methods for accelerating the improvement of crop varieties, is helpful to remember that cross-breeding methods have been generally used in crop improvement for at least a century to transfer new or improved traits from distantly related plant breeding stock into varieties that are specially useful for crop production. This now well established use of breeding stock from wild plant varieties that in itself, is useless for efficient food production, has in the past saved the worlds wheat supply from devastating fungal disease, and has been the source of semi-dwarf rice traits that powered the Green Revolution in Asia, and has enabled new highly productive rice varieties to be created by breeders.
Genetically modified crops (GM crops, transgenic crops, biotech crops)) represent the use of modern technology to bring about this time consuming transfer of useful traits in a better and quicker ways than older methods.
The general approach used in plant breeding is outlined in Table 1, which divides

breeding into three stages: useful trait discovery, cross-breeding between distant breeding stock, and *Elite* variety improvement stages. Each of these is time consuming and technically challenging, and improvements in each of the are needed to meet agricuture's challenges over the next decade.

Many different modern approaches to finding novel traits for crops are currently being explored. They generally offer a very decisive, advantage over older methods—they enable the breeder to dissecting out only desirable genes for transfer into Elite varieties and thus avoid introducing the many thousands of other often undesirable genes that are present in the donor organism.

Table 1. Old and New Ways of Breeding Crops

Stage	**Twentieth-Century Methods**	**Twenty-first-Century Methods**
Finding desirable traits	Searching among closely related species, Nature of trait poorly understood	Searching among wider range of species, completely detailed indexes to genetic composition of organisms that can be searched using computers, numerous alternatives for trait identification
Breeding with distantly related parents to generate potentially useful hybrids	Desired gene contaminated with thousands of undesirable genes Cross-pollination, interspecies and crosses inter-genus crosses rescued by laborious laboratories procedures (embryo rescue)	Genetic dissection to select only the desired new genetic material, Novel tools (gene ferries or‘vectors’) and methods for gene injection to enable single traits to be transferred into new hosts. New tools such as detailed genetic maps, genetic markers to speed up conventional breeding
Mating of novel hybrids with Elite varieties	Extremely time-consuming major hurdle for crop breeding	Gene cloning and marker technologies reduce this hurdle by minimising introduction of unwanted genes and reducing time and labour needed to regain Elite status. (Breeding is still needed to adapt hybrids to local conditions.)

A first step in breeding new crop hybrids is identification of the trait that needs to be improved—for instance, resistance to a fungal disease in a cereal crop. A search is then usually made for new breeding stock that displays intrinsic resistance to the particular fungus, virus or bacterium causing disease, and frequently it is found that plants consist of several or even many ‘races’ which display different attributes with regard to disease resistance. Very often it has been necessary to test wild relatives of the domesticated crop variety as a possible source of new genes, or even wild plants from other, more distant biological groups to find novel intrinsic resistance mechanisms to particular diseases. The practical details of breeding traits from such diverse biological sources into domesticated food crops are a major experimental hurdle because crosses involving different plant species are often infertile, and potentially valuable hybrid embryos need to be rescued using special laboratory and greenhouse techniques. Laboratory innovation to overcome this barrier to crop-improvement has been a feature of crop breeding for some sixty years but has only received wide publicity over the last 25 years.

If the parental stocks used in a plant-breeding programme are from the same species, cross-pollination to produce improved hybrids is much more straightforward. But there is another problem to consider. Existing domesticated crops have usually undergone extensive breeding to ensure that they are high yielding or have other desired traits to assist farming, such as suitability to local climates and soils, or resistance to local diseases (hence the term- Elite varieties). For example, resistance of maize to maize streak virus is especially important for preventing crop losses in Sub-Sahara Africa. Natural cross-pollination introduces thousands of new traits into the hybrid and many of them are undesirable and destroy the hard-gained advantages of the Elite varieties. Time and effort has to be spent in conventional breeding programmes to remove these undesired genes and it may take 5–10 years for a new crop to reach the market. Advances in DNA science have created new methods and concepts that allow conventional breeding to be done more speedily and efficiently.

The Driving Force for Genetic Modification—What Benefits Come out of Plant Breeding Research?

One of the driving forces encouraging scientists to continue trying new genetic methods to introduce novel traits into crops was dissatisfaction with the excessive use of synthetic chemical pesticides in agriculture, with their attendant problems of chemical persistence in the environment, pest-resistance, and risks to the health of farmers and others inadvertently exposed to pesticide spray. Insecticide misuse is a particularly serious problem in developing countries where farming is generally much more labour intensive than in Australia and North America, and where farmers are much more easily exposed to pesticide spray.

One of the extensively used alternatives to synthetic pesticides now provided by modern plant biotechnology are natural insecticidal proteins now present in many (transgenic) GM crops but originally produced by a bacterium called *Bacillus thuringiensis*. These insecticidal proteins are commonly referred to as “Bt proteins”. Transgenic crops contain novel genes that enable the crop to produce insecticidal Bt proteins in the growing plant and so protect the crop against insect damage. These crops include maize (grown in large areas of the USA, Spain, South Africa and South America) and cotton (grown extensively in the USA, Australia, China and India). The evidence (which started with Bt-cotton in 1996) from this substantial global experience with the Bt trait is that dramatic reductions of chemical spraying and substantial improvements in the environment levels of persistent pesticides are obtained because of the Bt trait in these GM crops. In Australia, for example, synthetic pesticide spraying of cotton has been reduced about 80% because of Bt traits which is now used in most cotton grown in Australia. based on 2003 data, In the US Bt cotton has reduced insecticide use by 1.5 million kg annually and Bt maize has reduced insecticide use by 1.7 million kg annually (National Center for Food and Agricultural Policy, NCFAP, www.ncfap.org).

Compelling evidence for direct benefits to developing countries of modern GM crops has been obtained from two years of farm-level trials in China that were reported in the journal *Science* in April 2005 by Jikun Huang and colleagues. These Chinese farm trials attempted to answer three questions: Does GM rice help reduce pesticide use in the fields of farmers? Do new GM varieties increase the yield of rice? Are there identifiable health effects on farmers who adopt GM rice varieties? The study involved 69 randomly chosen farm-holders and 397 rice production plots, and included farmers who chose to adopt new insect resistant GM varieties and farmers from the same villages who chose not to adopt GM rice. Farmers were were allowed to use pesticide as they saw fit after making their own periodic observations on the severity of pest-infestation, and were not directly supervised by technical specialists. Thus the results with these farm-level trials are a good indicator of how these insect resistant varieties might influence overall pesticide use in China if they become widely used.

Results from detailed surveys of these farmers show the main difference between GM -adopters and non-adopters is their level of pesticide use. GM-seed users applied pesticide *less than one-seventh* as frequently as conventional rice growers, and spent about *one-ninth as much on pesticides*. About 5% of farmers reported pesticide related illness after pesticide spraying on non-GM plots. No farmers in the study reported experiencing illness after spraying of a GM-rice crop. These results clearly show GM-rice does substantially improve both environmental stewardship and farmers health in China. Additionally better rice crop yields than with conventional seeds were obtained using insect protected GM rice. One of the rice varieties they studied was a Bt protected rice, and it gave 9% more rice per hectare than did the conventional rice varieties used in this trial.

This report on Bt-rice fits with previous experience obtained with the Bt crop trait in China, where it had been earlier found that GM cotton gave similar improvements in pesticide management. It experience with Bt-rice is important because it make it likely that China will eventually give regulatory approval to GM rice varieties, and if China approves commercialisation of transgenic versions of this staple food it will affect progress towards commercialisation of GM crops in other countries.

The Success of Bt-cotton in India.

Cotton is an economically important crop in India, where it is both a source of low-cost fibre for the textiles and cottonseed oil for cooking. The results of first three seasons (2001-2003) of practical commercial experience with Bt-cotton were a pleasant surprise. They showed that in India cotton-yield improvements from using Bt-cotton are much greater than in the other countries where Bt-cottons are used, which is actually understandable given the high insect pest pressure in tropical India. A dramatic jump in average national cotton crop yields for the 2003 season to an estimated 39% above the ten-year average is most compelling Indian statistic to emerge. This economic success of GM cotton in India is now spurring a wave of further crop innovation in that country to introduce the Bt trait into numerous other Elite Indian cotton varieties.

Maize- A Staple Crop in The Americas, Africa, and China

Maize is a staple food in Mexico and other parts of central America, China, and also in many African countries, where it was introduced shortly after Christopher

Columbus discovered America. The benefits from GM varieties of maize are a further illustration of modern genetics' the special value to developing countries.

One of the serious problems faced by poorer communities world-wide who rely on maize as a staple food is that mouldy maize may contain dangerous toxins that cause cancer and birth defects. Fumonsin is the major maize toxin that has been extensively studied and it is produced by fungi that are common on maize cobs. It was now known that fumonisin toxin interferes with mechanism by which the vitamin folic acid is taken up by human cells. Thus this maize toxin effectively induces the same vitamin starvation that is well established by modern medicine to cause the devastating birth defect *spina bifida*.

Medical studies have linked a high incidence of *spina bifida* birth defects in poorer, maize- tortilla eating mothers in North America and high rates of throat cancer in the maize-staple dependent Transkei region of South Africa, and a similar incidence of throat cancer in maize eating regions of China to the unfortunate prevalence too much mouldy maize as food by poorer people in all these regions of the world.

Upper panel:small-hold farmer Mr Rabie Mntungwa and his 2005 crop of GM glyphosate herbicide tolerant white maize in Kwa-Zulu Natal, South Africa. Lower panel: close up of white maize. Based on his three year experience with this new GM crop, Mr Mntungwa is very enthusiastic about its labour saving benefits [photo by the author].

Increased fumonisin toxin levels in maize kernels are known to be promoted by the increased mouldiness that occurs after damage to maize by insect pests such as borers. GM maize crops with the Bt trait offer maize that is protected from insect damage by borers and other pests and thus indirectly lowers the risk of birth defects and throat cancer by ensuring maize has lower toxin levels. Bt-maize thus offers a step forward to better health for poorer farm communities in central America and South Africa. African small-hold farmers are taking advantage of another important advantage offered by GM-maize varieties- greatly reduced labour needed for weed control.

One such farmer is South African Rabie Mntungwa of Kwa-Zulu Natal (see photo). Mr Mntungwa is one of a group of small-holder African farmers who have had experience growing new varieties of white-maize that tolerate the herbicide glyphosate. White maize is a variety of maize preferred by many Africans as their staple food because of its taste and colour. The glyphosate tolerance trait was introduced into this maize by genetic manipulation and conventional cross-breeding with african Elite varieties. Tolerance of herbicide saves these farmers hours of back-breaking labour, and particularly it saves African women farmers much heavy labour, as in their husband's absence earning cash income in distant townships, it is they who often have work the farm. The tolerance trait allows simple weed control with the non-persistent chemical glyphosate even after maize seeds have been planted. Mr Mntungwa and other farmers in his region of Kwa-Zulu Natal are very enthusiastic about the opportunities to earn income with labour-saving glyphosate tolerance because, to quote Mr Mntungwa “the herbicide tolerance makes all the extra work worthwhile”. He has hopes of buying a car with the extra income he expects from a bigger crop.

The glyphosate tolerant trait is particularly helpful for farmers the world-over who wish to practice the technique of minimum-tillage farming (also known as no-till or conservation tillage). Environmentally friendly minimum-till farming, in which plowing and tilling are largely avoided, is now more widely practiced in commercial farms of Australia, North America, South America, and South Africa as a result of genetic modification being used to introduce the glyphosate herbicide tolerance trait into Elite varieties of maize, soybean and cotton with substantial global benefits to the environment. These benefits include greater buildup of soil carbon (reducing carbon dioxide emissions to the atmosphere), buildup of soil nitrogen, better soil texture, and reduction of soil erosion (see Conservation Tillage Information Center, CTIC, www.ctic.purdue.edu).

Better nutrition for rice-eaters?

Golden Rice is another benefit of GM crop technology, still in the process of reaching its intended beneficiaries in developing countries, due to the slowness of regulatory agencies in the developing counties where regulatory approvals is needed for field trials.

Grains of Golden Rice compared with traditional white rice grains. The yellow colour is due to pro-vitamin A, and the new vitamin enriched rice has the potential for preventing 0.5 million of cases of blindness and more than 1.3 million deaths caused by vitamin A deficiency each year [photo courtesy of Dr Jorge Mayer, The Golden Rice Project, www.goldenrice.org].

Golden Rice is the name used for GM rice varieties originating from the work of biologists Peter Beyer in Germany and Ingo Potrykus in Switzerland, who in 2000 announced the transfer of traits from daffodils and bacteria into rice plants that gave rice grain ability to produce pro-vitamin A, a vitamin precursor also known as beta-carotene. Their pioneering work has tremendous human welfare implications because vitamin A deficiency is one of the world's leading causes of blindness, affecting some 100 -200 million people. Vitamin A deficiency also interferes with the body's immune defense against infections. Each day 6000 children die in the developing world because of poor vitamin A nutrition, and each year 500,000 go permanently blind. Since Beyer and Potrykus' first report about Golden Rice, much effort has gone into thoroughly testing their GM rice varieties, into developing varieties with higher vitamin content, and ensuring that this transgenic rice is suitable for use farmers in developing countries. In 2004 improved varieties of Golden Rice (containing about 6 microgram of pro-vitamin A per gram of rice grain) went through practical farm field trials in the USA, supervised by Florida State University. Golden Rice varieties are currently is being cross-bred with local Elite varieties using conventional breeding methods in India and the Philipines. The charter of the foundation *The Golden Rice Project* is to ensure that vitamin A enriched rice is made available to low-income farmers at no extra cost compared their conventional rice seeds, and that poorer farmers would be free to sell their rice on local markets.

One of the difficulties faced by this humanitarian initiative of misinformation spread by the environmentalist organisation Greenpeace that exaggerates by an order of magnitude the amount of rice that children would have to eat to get a benefit. At 6 microgram pro-vitamin per gram of rice, typical daily rations of Golden Rice should have significant impact on vitamin deficiency. Nutritional benefits of Golden Rice are easily and sustainably distributed, as all that is needed is contained within the seed, which can be passed on from farmer to farmer at little cost, and the rice requires no special fertilizer or resource not already used by white rice. Economic studies suggest that the potential welfare benefits of this rice to Asian counties would be US$15.2 billion a year.

In 2005 an exciting step forward in this effort to alleviate vitamin A deficiency was made by a scientific group from the plant technology company Syngentia. They announced the breeding of a GM rice, which they call Golden Rice 2, that produces 23-fold more vitamin A related nutrients than the first Golden Rice. This new variety depends on traits transferred into rice from maize instead of daffodils to achieve its higher vitamin content. It seems very likely that this new rice will deliver in one small 60 g child's portion of rice an amount of vitamin A that is close to the child's recommended daily allowance of 300 microgram, which takes any questioning of nutritional impact of this new technology off the agenda of the GM debate.

The Origins of Genetics and First Applications to Plant Breeding

In the twenty-first century, genetic modification is routinely carried out by modifying the genes within cells in a deliberate and direct way, and has been crucial for all the benefits that have just been mentioned. The outcome of experiments can be planned beforehand and new hybrids can be created by design, often with the aid of a computer and chemical synthesis of artificial DNA. This revolutionary technology had rather humble beginnings. They date back long before the science of genetics was conceived.

Jared Diamond's prize winning book, *Guns, Germs, and Steel: A Short History of Everybody for the Last 13,000 Years*, contains a fascinating discussion of how agriculture began near what is now Syria some 9000 years ago. Both inbreeding, or self-pollination, and cross-breeding, or inter-species hybrid formation, played an important role in the origins of our staple foods. Crosses between different species of flowering plants are, in fact, a common mechanism by which new species of plant originate. Bread wheat, for example, contains virtually the complete chromosomal sets from three distinct grasses whose relatives grow wild today in the Middle East.

Wild grasses near the Fertile Crescent contained a high percentage of hermaphrodite 'selfers'. These are plants that normally self-pollinate but which occasionally cross-pollinate. Such 'selfing' characteristics were exploited by the earliest farmers. Occasional variants (mutants) produced seeds with a favourable characteristic that made them more useful as foods. These variants were automatically favoured by farmers for use in the next season's crops as 'selfing' would give crops in the next season similar characteristics.

In the main cereal crops, ability to cross-pollinate is not confined to matings between individuals of the same species but can occur between species. Bread wheat, as mentioned before, is one such inter-species hybrid. It was originally generated in the Fertile Crescent thousands of years ago, and it is now the most valuable crop globally. Thus, both natural evolution and conventional plant breeding can generate massive numbers of cross-species, gene transfer events.

In short, several thousands of years of mostly unintentional, non-scientific selection of plant varieties for advantageous characteristics have led to modern varieties of cereals and other crops.

Genetics as a science. The concept of a gene as a particle of inheritance was formulated by Gregor Mendel in the 1860s. This concept was later extended greatly, so that we now know that the particles postulated by Mendel and others at the turn of the twentieth century are DNA molecules, and that genes are physically carried in the nucleus of cells. All of these conceptual advances greatly influenced and stimulated plant breeding and crop improvement, and have had a major influence on global agricultural productivity since the early years of the 20th century.

This practical breeding relies heavily on natural genetic diversity ('germ plasm') present in wild plant varieties, and by 1900, the first germ plasm collections were established. A solid empirical and experimental basis for the science of Genetics was put in place between 1900 and 1930.

The huge practical impact of this science of ‘Mendelian Genetics’on crop productivity is intimately connected with the ongoing contribution of modern genetics to global food security.(An excellent more comphrehensive discussion of this important topic is available in the modern agricultural science textbook *Plants, Genes and Crop Biotechnology* by M. J. Chrispeels and D E Sadova, Jones and Bartlett, 2003)

One major landmark in modern plant breeding was the discovery that natural genetic diversity in the naturally cross-pollinating native American crop maize is responsible for much of it's vigour in producing a good yield of grain. This advance came in 1908 when US plant breeder G. H. Shull made the astonishing discovery that crosses between different inbred lines of maize produced hybrid seed that yielded 300% more maize crop per acre than either parent. Maize (or Indian corn), unlike wheat is not a naturally self-pollinating plant, and this natural characteristic makes it specially suited for exploitation of hybrid-vigour by plant breeders. Inter-specific *hybrid* seeds that offer practical ways for farmers to better exploit this aspect of natural genetic diversity,

These hybrid seeds have encouraged the development of a commercial maize-seed breeding industry, first in America, and then in other countries such as Africa. Between 1940 and 1980 in the United States, per hectare yields of maize tripled and commercial seed breeders contributed greatly to this increase. Subsequently breeders have successful in developing ways of exploiting hybrid-vigour in other crop. Rice is naturally self-pollinating, but recently, Chinese plant breeders have invented ways of making artificial rice-hybrids , and these are now used for give improved food production in China

Wheat breeding. Deliberate cross-species gene transfer by pollination from related species of wild grasses into wheat actually began in 1930. The driving force for these experiments is the damaging susceptibility of wheat to serious, widely occurring fungal diseases known as rusts and smuts. McFadden showed in 1930 that the wild grass genes from emmer (*Triticale tauschii*) could be bred artificially into bread wheat (*T. aestivum*) to create the new variety 'Hope', which was responsible for one of the longest rust-free periods in the history of US wheat cultivation.
In contrast to maize, wheat varieties are usually developed by non-commercial breeding organisations.

DNA Manipulation.

Modern genetics involves much manipulation of DNA outside of cells as a technique to find out how living organisms work and to achieve practical outcomes like introducing new traits into crop plants. Three seemingly simple ideas form the basis of these procedures. They seem very simple but they required great brilliance, luck and hard work by many scientists to establish that they are indeed true.
These ideas are:

1. That fundamental genetic components of cells are chemical polymers that can be extracted from cells, chemically purified, analyzed, and put back inside living cells to re-direct their activities (discovered by Oswald Avery in 1944).
2. That the genetic material acts as precisely-stored, coded information used by cells to direct their activities (discovered by James Watson, Francis Crick and many other workers around the years 1952-1960).
3. That the genetic material can be deliberately rearranged relatively easily outside cells, in the test tube, by using certain enzymes extracted from cells, and that the rearranged information can be used by cells (discovered by Stan Cohen, Paul Berg, and other workers around 1972, and usually called recombinant-DNA technology, or genetic engineering).

These three concepts, discovered largely through academic research on bacteria, form the basis of our current ability to deliberately change genes inside cells. In a very real sense, much of the genetics that hits the headlines in newspapers today is a rerun of the bacterial genetics of the 1970s, albeit in much more complex organisms, using far more powerful procedures and on a much more financially ambitious scale.

The Red Queen

> ‘Well in *our* country’, said Alice, still panting a little ‘you’d generally get to somewhere else—if you ran very fast for a long time, as we’ve been doing.’
> ‘A slow sort of country!’ said the Queen. ‘Now *here*, you see, it takes all the running *you* can do, to keep in the same place. If you want to get to somewhere else, you must run at least twice as fast as that!’
>
> [Lewis Carroll, *Through the Looking Glass*, 1871]

The advances obtained from conventional breeding exemplified by hybrid maize and other high-performing cereal crops are not without their pit-falls, since over-reliance on particular Elite varieties (‘monocultures’) can lead to spectacular crop failures due to unrestricted spread of diseases such as smuts and rusts of cereals. One approach (already mentioned) which has been enormously important in managing these disease problems is to cross-breed Elite lines with diverse wild-grasses, which contain novel genes for disease resistance. The aim of such experiments is to combine new useful genes from the wild parent with the the many agronomically important genes from the Elite parent. It should be noted that several crops, e.g. soybeans, used in modern agriculture actually consist of numerous different Elite varies, each of which performs better in different localities.

The various breeding strategies have been enormously important in giving global food security in the face of ever increasing food demand since about the mid-1930s, when disease problems of monocultures first emerged and the world currently has adequate food supplies because of them.

But, unfortunately, parasites evolve too, and new forms of crop diseases constantly emerge to cause problems with existing disease-resistant varieties. Thus, crop breeder and pathogen are part of an ongoing race, in which the breeder, as the Red Queen suggested to Alice, if he or she wants to get somewhere ‘must run at least twice as fast as that!’.

Risks, Hazards and Other Objections to GM Foods

Many questions are raised about the risks posed by the artificial transfer of new genes into food crops. Perhaps most importantly, consumers will seek assurances that there are no unexpected hazards associated with eating these products. Other areas of risk debate centre on whether novel GM crops create significant environmental hazards or whether transfer of pollen from GM crops into biologically related natural species such as weeds will have detrimental effects.

There are several strong arguments supporting the opinion that transgenic crops that have passed regulatory scrutiny are at least as safe to eat , or even safer, than food from conventional crops.

First, the GM foods have passed comprehensive and objective government mandated assessment of safety, which in Australia involves the federal regulatory body Office of the Gene Technology Regulator (OGTR, see www.ogtr.gov.au) a body which was created in 2000 with a mandate to ensure that genetically modified organism do not pose hazards to human health or to the environment. The OGTR's guidelines apply to all genetic engineering work in Australia, and approval of any commercial GM crop involves the OGTR in extensive consultation with different organizations such as the Environment Minister, the food regulatory authority Food Safety Australia New Zealand (FSANZ), and authorities regulating agricultural chemicals (see regulatory process outlined at www.ogtr.gov.au). Crops from conventional cross-breeding (i.e. not involving genetic engineering) are not required to go through the same stringent review as GM varieties. For example, there are two herbicide tolerant breeds of oilseed rape (canola) called Imi and TT that are currently widely grown in Australia which were developed by traditional cross-breeding, and are currently used to make vegetable cooking oil, that were not required to go through any formal regulatory review with the same degree of rigour as the mandated OGTR scrutiny of similar herbicide tolerant GM canola oilseed varieties made using genetic engineering.

Second, numerous scientific academies worldwide have thoroughly considered the general issue of safety of GM crops and have consistently and repeatedly come to the same conclusion, namely that GM crops pose no special risks not already posed by conventional crops. One of the most recent and perhaps most comprehensive of these reviews was by a committee of the US National Academy of Science (United States National Academy of Sciences Institute of Medicine. 2004. Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects, http://www.nap.edu/catalog/10977.html.).

This broadly-constituted scientific panel gave careful attention to the chance that unexpected genetic changes might be present in a new crop. They explicitly concluded that GM crops are no different in degree of risk than conventionally bred crops in terms of the risk, and from some points of view are less of a risk. The US Academy noted that "Unintentional compositional changes in plants and animals are likely with all conventional and biotechnological breeding methods."

Third, conventional foods and existing agricultural practices are not risk free and, and a requirement that GM foods be proved to have absolutely zero risk before being used leaves communities unnecessarily exposed to the harms – eg pesticide spray drift, poor nutrition, soil erosion, clearing of forest for extra farms that that GM crops can prevent. Thus over zealous demands for risk avoidance create their own harms by delaying benefits. Many of the 6000 children who die each day from vitamin deficiency would live if Golden Rice was not held up by cumbersome regulation.

And as the US National Academy of Science 2004 report points out, in conventional breeding:

> "selection [of plants] for desired traits, such as reduced levels of chemicals that produce unpalatable taste, may diminish the ability of plants to survive in the wild because they are also more attractive to pests. Selection for other traits, such as [the presence of] chemicals that increase the resistance of plants to disease, may also be harmful to humans. Another approach, crossing, can occur within a species or between different species. For example, the generation of triticale, a crop used for both human food and animal feed, arose from the interspecies crossing of wheat and rye. Because most crops can produce allergens, toxins, or antinutritional substances, conventional breeding methods have the potential to produce unintended compositional changes in a food crop."

The US report documents several examples of new plant varieties created by convention breeding which were toxic- eg the toxic Lenape potato, and celery that produces skin rashes.

This different management of GM and non GM breeding is also illustrated by a GM food problem arising from a Brazil nut protein, whose gene was inserted into soybeans by Iowa-based company Pioneer Hi-bred in the hope that it would provide an improved nutritional profile of essential amino acids. Unfortunately, the particular protein selected was later found to cause reactions in the blood serum of people allergic to Brazil nuts and, not surprisingly, the GM soybean also provoked these adverse allergic reactions. As a result, this novel food has not entered the marketplace. It is worth noting that such screening is not possible with conventionally bred hybrids, as thousands of unidentified new protein antigens are introduced in the 'natural' hybridizing process.

On the other hand, selection and marketing of natural varieties of potato and celery, which had conventionally bred improvements to pest resistance, have in the past led to the selling of foods that were downright hazardous. Relatively little fuss was made about them and they were withdrawn from the market. ‘Many of the nightmares predicted for genetically engineered crops have already happened [in non- GM crops]’, comments Tony Connor of the New Zealand Institute of Crop and Food Research.’. Conventionally bred potatoes and celery still appear on supermarket shelves without warning labels.

The above examples illustrate how public perceptions of risk are biased by the media’s need for new stories which give undue attention to minuscule risks from pesticides and hypothetical fears of gene technology. For instance, an objective assessment of the relative risks of eating food suggests that microbial contamination is a *million fold* times more damaging than pesticide residues. More than 20 per cent of Australians suffer from microbial food poisoning each year, yet these anti GM food biases actually get in the way of better public health and better environmental management, if only by diverting attention and investment from sensible priorities.

Worries about supposedly unnatural gene movement.

One persistent and often voiced worry about transgenic crops, that is about crops that have genes from another species inserted in them, is that by moving a new gene into a crop from another species some natural biological law is being broken, and thus we are facing a novel risk never before seen in nature. A diametrically opposite worry is a concern that genes in transgenic crops may accidentally escape to other organisms, and for example, move from plants back to bacteria and thus cause harm.

A moments reflection on these two worries makes it clear that they are inconsistent with one another: if movement of genes from a plant to a bacterium does in fact occur in nature, as the people who worry about adverse consequences of gene escape suppose, then some gene flow must occur naturally between species. It thus logically follows that inserting a gene in a new species is a process that occurred repeatedly in nature prior to the time when biologists started of deliberate genetic engineering in the laboratory.

These confusions become clarified when one realises that gene movement occurs in nature between many different organisms, by many different mechanisms, and at very different frequencies. The gene exchange process most humans are familiar with, that is conventional sexual procreation - symbolised by the catch phrase “birds and the bees” - is not the only way genes move in nature. The obvious conventional mating process found with mammals and cross-pollinating plants of course, generally occur every generation, while less well known mating processes, between bacteria, or between bacteria and plants, may occur less often than one in ten-thousand generations, and other classes of genes movement between, from plants to bacteria, or humans to bacteria, or movement carried out by viruses, for instance can be much less frequent and are still be theoretically possible. They can however be detected using advanced genetics techniques and are discussed widely by professional geneticists. Occasionally then, during evolution, genes do in fact move between different organisms, but the frequency is so low that it doesn't necessary a significant risk.

Genes move around within a species too!

On the other hand, random gene rearrangement within the one organisms are relatively common and are part of the natural level of genetic risk posed by natural genetic variation in food crops. Numerous natural genetic rearrangement have occurred during conventional breeding of the major food crops, for example rice. Nobel prize winner Barbara McClintock is famous for initiating a new era in genetics, which flourished from the mid-1970s onward. McClintock's work made biologists realise just how much random gene movement is going on within cells, and her poineering work has been abundantly confirmed by later studies

This natural random DNA rearrangement plays a very significant role in natural evolution of all plants and animals. For example about 37% of human DNA consists of this genetically mobile category of DNA. The natural mobility of this DNA is very similar in many aspects to DNA rearrangements exploited by genetic scientists in the laboratory. Extensive scientific knowledge about natural DNA rearrangements is part the carefully considered scientific conclusion mentioned earlier that risks possessed by GM-foods are similar to those displayed by conventional crops.

One of the sources of misleading discussion of this topic is the ‘reproductive isolation’ or species concept taught in school biology, which describes species as populations of mating organisms that are isolated by mating barriers from one another. This is merely a conceptual model which is used to improve understanding of how creatures evolve in natural populations. It is not a prescription for what *ought to be*. Many organisms behave in nature in ways that does not conform to any rule that species must be reproductively isolated from one another—this is especially true for

flowering plants, which very often form hybrids or new species – wheat and triticale are examples - as a result of natural cross-pollination between species.
Such interspecies cross-pollination, carried out artificially using conventional technology, has in the past yielded several new foods, e.g., nectarines and boysenberries, and as already mentioned has been used extensively by plant breeders to improve a wide range of food crops.

Environmental consequences.

One widely touted concern about GM crops is the escape of genes from them into other species via pollen. This process is not unique to GM crops, and large-scale raising of cultivated plants has always resulted in gene transfer to natural populations in those instances where there are related natural species. There are at least 16 documented cases of pollen cross-fertilization between conventional crops bearing herbicide or pest resistance genes and natural species. This scenario is of greater concern when the relatives are weedy and, in general, it is the Brassica family, including Canola (oilseed rape), in which it is common to find widely distributed wild/weedy relatives. When the gene introduced into a plant variety offers some specific growth advantage (e.g. insect resistance due to the Bt gene), such movement of pollen has potential for adverse environmental consequences. On the other hand a trait like vitaminA content present in Golden Rice yields appears to offer no conceivable ecological advantages in nature. (And since the red colour of carrots is due to this trait it is interesting to note that since the red carrot containing pro-high vitamin A in appeared as a spontaneous mutant in a Dutch garden in 1438 the has not spread to wild relatives of the domesticated crop, which remain white to this day).
It is pertinent that different cultivated crops have varying abilities to produce pollen, and varying abilities to cross pollinate. For example the rice flower is closed and rice is self-pollinating, whereas maize is a cross-pollinating plant. Whether or not there are related wild-species nearby also needs to be considered, as many domesticated plants are grown well away from their original geographical location, and thus have have no known natural related species in particular locations. Hence a pollen transfer scenario in these cases offers minimal risk. For example, genetically modified carnations have been developed by the Australian company Florigene, but these cannot effectively cross-pollinate, and have no relatives in Australia to which genes can escape by this

route. Similarly, cotton in many regions of Australia has no native species of the genus Gossypium with which it can exchange pollen. Pineapple plants also do not cross pollinate with other plant species found in Australia.

Human Emotions and Yuk factor.

Human emotions, moral judgments of value, and dietary laws handed down by religious tradition, rest on a different set of assumptions and rules to scientific assessment of nutrition and ecological impact, and it is quite likely that humans have innate psychological and emotional drives that make them very suspicious of any unusual features of a food (as entertainingly discussed by human behaviour expert Steven Pinker in *The Blank Slate).* Such customs and convictions are obviously very important influences affecting opinions about foods.

But they are not new objections. At the turn of the 19th century, people objected to the creation by plant breeders of new fruits such as nectarines and boysenberries on the grounds that the creation of new species was God's work, not Man's. For about two hundred years or so the tomato did not gain acceptance as a food in Europe when it was first introduced because of suspicions abouts its red colour.

One of the unsettling aspects about new GM foods is that they require rethinking of the reasoning behind judgments which involve religious dietary rules, and other deeply held human instincts. Consider the question ‘If I introduce a pig gene into chickens, and eat the meat of the modified chickens, am I eating pork?’ which represents a common concern of this type. Genetic knowledge can help refine the question by telling us that it is not the mere fact that the gene comes from a pig that makes it necessarily distinctive, because when one focuses on individual genes, a substantial part of the DNA from a pig is essentially the same as that of the chicken, and perhaps the objection to pork is better related to the behavioural habits of the pig and its susceptibility to parasites, which are not determined by a single gene.

Balancing Risks on the Backs of the Poor.

Amir Attaran and colleagues have persuasively argued in a July 2000 medical journal article entitled “Balancing risks on the backs of the poor” that in tropical developing countries thousands of people are dieing unnecessarily from malaria for relatively little proven gain in human health in order to satisfy rich nation's wishes to avoid risks from the chemical insecticide DDT. The debate about risks of GM crops echoes many of the disquieting features of the debate about use of DDT in developed countries highlighted by Attaran. In both cases, highly precautionary regulations and policies originate from popular political movements in rich counties and exert detrimental effects on the welfare of poor people in developing countries. The harms from the regulation are not borne by those who advocate the regulation

In the case of GM crop technology much of the policy and political power that is slowing down improvements in developing nation welfare from use of new crop technology originates in Europe. In Namibia, for example the threat of EU trade barriers on meat exports is preventing Namibian companies from feeding cattle GM maize grown in South Africa, and Norwegian agencies are strongly involved in Zambian governments anti-GM policies, which led in August 2002 Zambia to controversially reject US Food aid during a food supply emergency in that country. These numerous activities of European organisation in developing countries are morally questionable as they also serve to reinforce de-facto trade barriers which further the interests of highly subsidised EU farmers rather than than merely human welfare in developing countries.

There are of course reasons for requiring DNA-manipulated plants to be subject to special regulation to obtain more familiarity with a new technology under large-scale actual conditions of use, and also to understand the detailed consequences of a far-reaching technology involving products that are released to multiply and evolve in the environment. The purposes of such a regulatory strategy are to ensure that any benefits it offers are not canceled out by major unanticipated risks.

It is to manage these possibilities that many countries, including Australia, require work on transgenic organism to be reviewed by regulatory agencies. From this point of view, regulatory oversight is required to provide an ordered and gradual implementation of a technology so that we can identify the problems and gain familiarity with the organisms.

But it is also important to make sure that benefits of technology are not canceled out by major unanticipated delays, and regulatory inefficiencies are now a major barrier to timely provision of beneficial crops to poorer communities. This is well as illustrated by the fact that it was quicker to field test Golden Rice in the USA than to arrange for field trials in South Asia where it is most needed. The additional complication is that political concerns about effects of GM crops on trade barriersare adding substantially to regulatory delays, with the net effect that bureaucratic inertia and protection of subsidised agriculture in richer nations is now more of a health hazard to developing countries than is novel crop technology.

By looking ahead over the next decade, prospects for resolution of this vexing general issue of GM crop technology can be identified. First, a solid track record of environmental benefits from GM crops is being established by the GM technology leaders, and the Australian cotton industry is a major player in this encouraging trend. Several more seasons of low synthetic pesticide use in the main cotton growing counties who use Bt-cottons, and publicity about greatly reduced synthetic insectide spraying on Bt-maize and hopefully Bt-rice will establish unequivocably where the environmentally responsible path lies.

Second, in this coming decade, GM crops that provide clear nutritional advantages will have had an effect on food markets. Biofortified vitamin A rice and low-fumonisin maize have been mentioned, but to these will be added new cooking oils with healthy omega-3 polyunsaturated fatty acids. Omega-3 dietary acids have important roles in human health and are implicated in prevention of cardiovascular and inflammatory disease, mitigation of Altzheimer's disease and enhancement of intelligence, and are dietary fatty acids currently obtainable in fish products. These prospective health benefits, plus the cachet of saving fish stocks from over exploitation should make such novel oils from new GM plants- e.g. cotton and soybean - popular in both developed and developing countries.

Lastly, as the decade progresses, efficient use of existing arable land, and preservation of rain forest, wilderness and marginal lands from cultivation will be an increasingly obvious environmental imperative. GM crops generally, by underpinning ongoing improvements in crop yield that allow increase food demand to be met without expansion of farms, will play a major role in environmentally responsible land management, and this will be especially true in developing countries where land and water resources will be pressed to the limit.

Conclusions

As the second decade of GM crop usage begins, the reasons for using GM crops now include better health and cleaner environment in poorer communities in the developing world, healthier staple foods with lower fumonisin toxin levels, fewer pesticide poisonings, more productive farms, less weeding, prevention of blindness, and improved immunity to infectious disease. The now well documented economic and environmental benefits from a decade of experience in using transgenic crops in the technologically advanced agricultural countries provide confidence that the benefits outlined for developing nations will prove to be substantial.

The continued growth, year after year, of total planted GM crop area is the strongest proof of economic benefits from GM crops. The organisation ISAAA (www.isaaa.org) reported that 2004 was the ninth successive year of growth in global GM crop area, with an increase of 20% to 81 million hectares. Estimates of the net financial benefits to the US of GM crop technology place it at US$ 1.9 billion per year (NCFAP, www.ncfap.org)

Additionally GM crops are providing impetus to no-till (conservation tillage) farming with proved environmental benefits. The main GM crop worldwide is herbicide tolerant soybeans, grown widely in North and South America, and the availability of GM herbicide tolerant soybeans is the main reason soybean farmers in the US have adopted conservation tillage. This change minimises erosion and builds up soil carbon, and saves on fuel used for ploughing. The widely grown carrying the Bt-trait - Bt-cotton in Australia, the US, China, South Africa and India, Bt-maize in the USA, South Africa and Spain, have led to massive reductions in synthetic pesticide use world wide.

There is a compelling argument for trying to save 6000 children who die each day due to vitamin A deficiency, and for them GM rice offers real hope. Golden rice could potentially improve welfare in Asia to the extent of US$15.2 billion a year and is emblematic of the value of GM crops to the developing world. The main purpose of Government regulation of GM crops is to prevent unintended adverse consequences canceling out their benefits. It is now becoming obvious that we also need to guard against unnecessary bureaucratic inertia and political interference canceling out the GM crop benefits. The coherent arguments in the United Nations report *Making new technologies work for human development* that is quoted at the start of this current article could help move the world in this direction.