GMOs and Society

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Abstract

The discussion on GMOs and society is constructed around 12 major questions that have polarised debate on the subject, namely:
What is the current status of GM crops, particularly in the Australasian region?
Are the net economic benefits of GM crops likely to be positive or negative?
Can the “Precautionary principle” ever be consistent with “Substantial equivalence”?
How important are GM crops likely to be in poverty reduction in developing countries?
Are the overall environmental benefits of GM crops positive or negative?
GM crops – health hazard, health wonder or mostly irrelevant?
Who really benefits – big business, farmers, or consumers?
IP management – necessary for research and investment in GM crop development or only a tool for the rich to get richer?
Labelling and segregation chains – consumer right to choose or unworkable apartheid?
Can regulatory systems evolve that can please everyone?
Is it possible not to take sides - Why is there so much opposition?
Hope or hype? Has the technology been oversold? Is universal adoption inevitable?

Media summary

This paper summarises some of the arguments that are currently used for and against production of genetically-modified (GM) crops. It proposes a likely scenario akin to that for nuclear energy, in which some countries will be strong adopters while others will not adopt GM crops even after the technology has been available elsewhere for several decades.

Key words

Genetically modified crops, biotechnology, society, economic benefits, biosafety, developing countries

Introduction

The introduction of genetically-engineered crop varieties has been described as the most rapidly-adopted technology in the history of US agriculture. And, in recent years, adoption rates in a number of other countries have been significant. However, genetic modification has also been one of the most controversial technologies yet introduced in agriculture, with many governments limiting the adoption of GM crops, especially those crops intended for food rather than for fibre use. Society is becoming increasingly interested and involved in issues surrounding the development, use and safety of new crop varieties. This plenary paper addresses many of these important global issues. The focus of the paper is not the science of gene manipulation or specific applications of the technology, but rather an analysis of the broader issues of debate on benefits and disbenefits of GM crop technology. A key issue is that rather than sweeping generalisations be made for or against the technology, it is important for each GM product to be considered on its merits, in a similar manner to the approaches used for evaluation of agrochemicals or pharmaceuticals. Conventional breeding of better-adapted, more nutritious crops has underpinned the supply of food for an ever-increasing world population. There is uncertainty, however, as to whether such procedures can continue to meet this demand. This is particularly relevant to ACIAR’s role as a facilitator and funder of agricultural research for international development, wherein we as an agency are routinely required to compare potential research investment options and their relevance to poverty reduction.

What is the current status of GM crops, particularly in the Australasian region ?

The most recent statement on the “Global status of GM crops” published by the International Service for the Acquisition of Agri-biotech Applications (ISAAA; James 2003) showed a 15% increase in the area sown to GM crops over the preceding year to a total of 68 million ha. GM soybeans continue to predominate on an area basis, with an increase of nearly 13% to represent 55% of soybeans grown. There was a growth in the area planted to GM maize, with an increase of 25% to a total 11% of the global maize area. Canola followed with 20% growth for a total of 16% area globally. GM cotton was up 6% to 21% of the global area. Within the next five years, ISAAA predicts that 10 million farmers in over 25 countries will plant 100 million ha of GM crops. The global market value of GM crops was approximately USD $4.5 billion in 2003. Adoption in developing countries is increasing steadily, and there actually is now a greater number of farmers in developing countries growing GM crops than in developed countries - a factor often overlooked by those who doubt the applicability of the technology to the poor. However, the range of crops available commercially has not widened over the last 5 years. Herbicide tolerance is the dominant trait followed by insect resistance. Brazil and South Africa joined the United States, Argentina, Canada and China as the leading growers of biotech crops. China and South Africa experienced the greatest increase, with both countries planting one-third more hectares of GM crops than in 2002. Remaining countries planting more than 50,000 ha are Australia, India, Romania and Uruguay; another eight countries each planted up to 50,000 ha of GM crops. In Australia, GM cotton areas dropped slightly, to about 100,000 ha as a result of the 2002/03 drought. The report also stated that 7 million farmers in 18 countries now plant GM crops. Almost one-third of the global GM crop area was grown in developing countries.

Moreover, the attitude to GM crops in Europe is softening albeit only slowly. Although small amounts of GM Bt (*Bacillus thuringiensis* toxin-producing) corn is grown in countries such as Spain, most of Europe has had a *de facto* moratorium on GM crops since 1998-99, when five member states issued a declaration that they would effectively block new GM approvals until there was new EU law on labelling and traceability. These laws have now been put in place (Brookes and Barfoot 2004), and include rules governing the biosafety approval of field trials and the growing of GM crops and laws on the labelling a traceability of GM crops. As of May 2004, the European Commission has approved importation of BT-11 sweetcorn into the EU. This will mean the end of the *de facto* ban on GM foods in Europe. The corn will only be imported in canned form, meaning that it is not viable as seed. The particular corn line had been approved as animal feed and its derivatives, such as corn syrup, were approved for human consumption before the EU halted its approval process in 1998. The major issue currently under negotiation in Europe, affecting potential field trials of GM crops is the establishment of rules governing the permissible proportion of GM material may occur in non-modified seeds before they require labelling. The UK Government has also recently approved the planting of GM corn for use in cattle feed.

While Europe may not need GM crops for food security or to seek related production efficiency gains, there have been other significant consequences of the European approach. One has been the negative effect of the moratorium on crop biotechnology research investment in Europe. Another problem is the impact of European policies on the rest of the world, including several developing countries. These countries are sometimes reluctant to invest in GM technology at the risk of jeopardizing current or future export markets, and may not have the necessary segregation technology and infrastructure to comply with the labelling and traceability demands of the EU.

The current status of GM crops in Australia

The *Gene Technology Act 2000*, which came into force in June 2001, introduced a national scheme for the regulation of GMOs, namely the Australian Gene Technology Regulator (www.ogtr.gov.au). When the Act was created, it was a deliberate measure to confine the Regulator's powers to deal exclusively with health, safety and environment issues. This was to ensure that the assessment of health and environmental risks cannot be compromised by economic issues such as farmer incomes and the marketability of crops. Currently a number of GM foodstuffs can be imported into Australia, but the only crops approved for commercial production are not food crops, but cotton and carnations. However, a wider range of GM food products is available in Australian supermarkets, coming from imported sources – soybean, canola, corn, potato, sugar beet and cottonseed oil.

In 1996, GM cotton with a single Bt gene, was grown commercially in Australia for the first time to enable *Helicoverpa* bollworm control. Average reductions in pesticide use of over 50% have been reported. Glyphosate herbicide-resistant cotton and combined glyphosate/Bt cotton were made commercially available in 2001. In 2003, cotton with two Bt genes was approved. While the main product of cotton production is fibre, cottonseed oil is used widely for fried food preparation and cottonseed by-products are used widely as animal feed. A number of GM crop field trials are underway (or applications made for such trials), including as of early 2004: cotton (with modified fatty acid (high oleic) content in seed oil; tolerance to the herbicides, glufosinate ammonium or glyphosate; insect resistance with the vegetative insecticidal protein gene); grape vines (with potentially altered berry colour, sugar composition, flower and fruit development); pineapple (reduced blackheart defect and delayed flowering); papaya (delayed fruit ripening); canola (herbicide-tolerant hybrids); sugarcane (reporter genes); oilseed poppy (altered alkaloid production pathway); white clover (alfalfa mosaic virus resistance); lupin (high sulfur grain). Other recent field trials of GM crops in Australia have included field peas, wheat, barley, roses, Indian mustard, lentils and tomatoes.

At the national level, Australia has developed clear regulatory systems for the production of GM crops as well as food labelling laws. However, with the exception of Queensland and Northern Territory, each of the Australian states have introduced moratoria on their production – either on all commercial GM crops or on commercial GM food crops. The bans do not affect research (and paradoxically come at a time when many states are vigorously supporting biotechnology research) but they seriously affect the implementation of the results of research. Without the conduct of large-scale trials it is impossible to generate data that will test the environmental effects of crops such as GM canola (and the capacity to segregate GM and non-GM grain) or would enable farmers to make informed investment decisions. The bans particularly affect the potential introduction of GM canola rather than cotton (as unlike the other states with moratoria in place, NSW, a major cotton-growing state, has not restricted GM fibre crop production).

Case study: GM oilseed rape (canola) in Australia – will it rape the environment?
As mentioned above, the greatest controversy in Australia surrounds the potential commercial release of GM canola in Australia. It also highlights the point that regulatory approval and consumer acceptance are quite different things. In July 2003, a licence for the commercial release in Australia of Bayer CropScience's InVigor® hybrid canola was issued. This is a hybrid that has been genetically modified for tolerance to the herbicide, glufosinate ammonium. In December 2003, a licence for the commercial release of Monsanto's Roundup Ready® canola, tolerant to the herbicide glyphosate, was also issued. Roundup Ready® canola oil has been assessed and approved for human consumption in Australia by Food Standards Australia New Zealand (FSANZ). The Australian Pesticides and Veterinary Medicines Authority (APVMA), which is responsible for the registration of agricultural chemicals, also approved the use of Roundup® herbicide for weed control in these canola crops. During the evaluation, concerns were expressed about possible economic and market impacts if Roundup Ready® canola spreads to adjoining farms, but it was concluded that unwanted GM canola plants can be effectively removed with a range of weed control methods.

In Australia, a number of issues with GM canola remain poorly resolved, partly due to the ongoing uncertainty surrounding whether individual state governments will ever permit GM food crops to be grown, along with mixed international market signals (Leading Dog Consulting and Synecon Pty Ltd 2003). Australia is the second largest exporter behind Canada, and exports from Australia account for nearly 75% of production. Canada is the major world exporter of canola with 75% of its production genetically modified. Most Canadian exports are undifferentiated, as their major export markets are not prepared to pay for costs of segregation. Markets such as China, India and Mexico will not pay premiums and appear not to be requesting non-GM products.

Industry groups argue that costs and management undertakings with GM canola will be outweighed by the agronomic, economic and environmental benefits, and that the Canadian experience has shown that the environmental challenges can be adequately managed. In a study carried out on behalf of Australian industry (Norton 2003), evidence was provided that introduction of GM canola in Australia would significantly reduce the use of (persistent) triazine herbicides, much more canola would be grown under direct drilling or minimal tillage practices and average canola yields and areas sown would increase. Yields of wheat would benefit due to the value of canola as a disease break crop. Modelling work carried out by Foster (2003) suggests that even if segregation costs and technology access fees are high, the net economic benefits of adoption of GM canola will remain strong. Representatives of the canola supply chain, under the Gene Technology Grains Committee, have proposed principles by which GM canola could potentially coexist effectively with other canola production systems. GM canola growers would be required to follow crop management plans with recommendations for on-farm planning and record keeping. However, concerns about potential negative environmental effects of GM canola (such as outcrossing with weedy relatives or with non-GM canola, e.g. Rieger et al 2002) and more particularly to the "clean, green" image of Australia primary products have been the main factors behind many Australian States placing a moratorium on commercial plantings of GM crops. In mid-2004, the two biotechnology companies involved announced that they were withdrawing from field trials of GM canola in Australia, as well as trials of other GM food crops.

Are the net economic benefits of GM crops likely to be positive or negative ?
Many of the earlier studies on this subject were *ex ante* analyses (predicting likely benefits), but there is now sufficient experience with GM technology that it is more instructive to rely on *ex post* analyses (of actual benefits). Of course, most of the data relates to North American conditions and may not always be able to be extrapolated, especially to developing countries. The studies also suffer from using data derived from only a couple of seasons, and some of the economic benefits of practices from reduced tillage using GM herbicide-resistant crops can take some years to manifest. Results generally show improvements in profitability, but not always – for example, when there is little pest pressure in a particular season, the additional costs of purchasing the GM seed may not be warranted. Profit is more important than yield increases alone if the GM crops can enable significant decreases in input costs. This seems to be more the case with BT corn (Furtan and Holtzman 2001) than with BT cotton, where many studies (but not all, e.g. Marra et al. 2002) show quite positive net economic benefits from the GM crops through yield gains and reduction in pesticide inputs (Carpenter and Gianessi 2001; Huang et al. 2001). A study by the (US) National Center for Food and Agricultural Policy (Gianessi et al. 2002) of GM crops showed consistently positive benefits (aggregated for farmers, consumers and seed suppliers) with adopted pest-resistant varieties of corn, cotton, canola, soybean, papaya and squash crops in the US providing benefits of USD $1.2 billion in 2001 alone, as well as environmental benefits from significant savings in pesticide use.

With herbicide-tolerant corn and soybeans, yields may not always be higher because the GM herbicide-tolerance trait may not have been initially introduced into the particular variety that is highest yielding under the growth environment. Often the cost of the seed and the savings in herbicide cancel each other out, although several studies do not include the labour and fuel savings in reducing herbicide applications. Many, but not all studies show benefits for herbicide-tolerant canola (Stone et al. 2002). Weeds are estimated to cost Australia over $ 3.5 billion annually (Plant Health Australia 2002), and herbicide tolerant crops make conservation farming – to conserve soil and soil moisture and structure - using herbicides for weed control easier. Herbicide tolerance is the most widely incorporated character in GM crops worlds-wide (Gene Technology Task Force 2002). GM herbicide tolerance can be engineered through alterations to the receptor target site for the herbicide, over-expression of the receptor or introduction of an *in planta* detoxification system for the herbicide. It is often not recognized by opponents of GM technology that there are a number of non-GM herbicide tolerant varieties of major field crops grown routinely, and that some of the environmental risks of GM herbicide crops remain issues for all herbicide-tolerant crops. In Australia, a significant proportion of the canola crop are imidazolinone- or triazine-tolerant varieties. In both cases, herbicide-resistant weeds can be a problem. But in international studies, the relative profitability to farmers of using GM herbicide-tolerant crops seems to be variable, and depend on the seasonal conditions and weed loads.

Do smallholder farmers in developing countries benefit economically from GM crops? Studies by Pray et al. (2002) on BT-cotton in China showed that compared with conventional cotton there was greater production efficiency (slightly higher yields) and significantly decreased use of pesticides. The latter gave both health benefits and a 20-30% reduction in production costs – saving over $400 m annually. Small farmers gained proportionally more benefit than larger ones, and recent adoption was favoured by deregulation of cotton prices and entry of private seed companies. The decision on whether GM rice will be released in China is key – herbicide-tolerant rice was available for release in China for some years but as a food crop the Chinese government has shown a more conservative approach on biosafety with rice. Various groups have modelled potential impacts of commercialisation of GM cotton and rice in China showed that potential gains are substantial, and mainly occur inside China.

Anderson and Nielsen (2002) reached a similar conclusion modelling a broader range of crops and international regions. Gains from a 5% increase in productivity greatly outweigh potential exclusion from some export markets, although GM food labelling would significantly lower economic gain. Potential gains from GM cereal crop adoption exceed those for cotton. As mentioned above, the critical cereal in this analysis may well be rice, the most important cereal crop, particularly for developing countries. Agronomic improvements (higher yield, disease resistance) and nutritional enhancement both hold potential. Herbicide, bacterial leaf blight and yellow stem borer resistance are the traits closest to commercial release, while varieties with blast, brown plant hopper or virus resistance, improved vitamin A and iron bioavailability, tolerance to abiotic stress and with increased panicle numbers are under development. Brookes and Barfoot (2003) have argued that acceptance of GM rice in the developing world, particularly China, could be the catalyst to widespread adoption of GM crop technology. Rice is traded far less than other cereals, so countries will mainly look at potential benefits for their own producers and consumers (decreases in food prices for the urban poor) in making decisions about adoption of GM rice, and of those countries that do import rice, they are overwhelmingly developing countries.

Can the "Precautionary principle" ever be consistent with "Substantial Equivalence" ?
There are two broad approaches that underly options for regulation of GM crops – the precautionary principle and substantial equivalence. The precautionary principle arose at the 1992 Rio Environment conference (www.un.org/documents/ga/conf151/aconf15126-1annex1.htm) and states "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason to postpone cost-effective measures to prevent environmental degradation". To turn this around, the principle states that "a new technology should not be introduced unless there is a guarantee that no risk will arise" (Nuffield Council on Bioethics 1999, 2003). This underpins the EU's view that GM crops are new products and should be subject to separate and higher safety approval standards than conventional products. However, the Nuffield Council concluded that "in our view such a principle would lead to an inappropriate embargo on the introduction of all new technology". In the author's view, a major shortcoming of the precautionary principle is that it fails to take into account the implications of inaction – for example, the high rates of pesticide poisoning by cotton farmers spraying conventional crops in many developing countries. The need for all countries to have functioning biosafety systems has increased since the adoption in September 2003 of the Cartagena Protocol on Biosafety, an international framework for regulating trade in transgenic crops. The Protocol will have implications for individual countries in trade as users, developers and exporters of GM crops. It specifies that international shipments that "may contain" transgenic food products must be so labelled. This does not affect labelling requirements on consumer products, which are determined by each country. However it states that Governments may use the "precautionary principle" to bar import of a transgenic product even in the absence of conclusive evidence that the product is not safe. However, the protocol does not override other international agreements, including those under the World Trade Organization, which require that import decisions be science-based.

Substantial equivalence treats GM crops as no different from new conventional crops, if the food so derived is "substantially equivalent" in composition, nutritional value and intended use. Thus the US Food and Drug Administration only requires GM foods to receive pre-market approval if they are not substantially equivalent. This approach can be summarized in the statement "We should judge the safety of individual products that are the applications of a new technology rather than the technology itself" (Chassy 2002). Reconciliation of these two approaches – if ever possible – seems the key to the way forward. Bodies such as Food and Agriculture Organization of the United Nations, World Health Organization and the Codex Alimentarius Commission are attempting to play an honest broker role and should assist international negotiations on trade in GM food crops. Jaffe (2004) reviewed regulatory processes used in different countries and concluded that the best combination of product safety and public trust is achieved when the system is mandatory and pre-market, and uses established safety standards and processes that allow for public participation with no preconceived biases.

How important are GM crops likely to be in poverty reduction in developing countries ?
In many developing countries the initial rates of grain yield improvement from the "Green Revolution" were not sustained after the mid-1980s. In several African countries it had limited impact, largely because the high-yielding varieties were tailored for favourable environments in which irrigation, reasonable soil fertility and affordable fertilizer was available. World population is forecast to increase by 50% in the next 50 years, almost exclusively in developing countries and without access to new land for exploitation. This together with dietary change - the increasing consumption of livestock products and use of grain crops for livestock feed - means that food security concerns for the future remain. Some opponents of GM

technology have stated that lack of food and inadequate nutrition is a political and economic problem and does not require increased productivity – in other words, there is enough food in the world but the problems are due to distribution and access. However, use of food aid and other programs to redistribute this food would not provide sustainable poverty reduction and would create greater, rather than less, dependence on aid. Much of the reduction in poverty in East and South Asia during the last few decades was triggered by sustained increases in agricultural productivity. While GM crops are only one of a number of alternatives for productivity increases in some situations they have the potential to address major problems that have proven recalcitrant to traditional plant breeding approaches – such as pest resistance in cotton (Serageldin and Persley 2000; ADB 2001; Persley and Doyle 2001; Skerritt 2001). An unresolved issue is whether developing countries need biotechnology to provide a "quantum jump" in productivity or whether improvements in agronomy can provide this (Altieri and Rosset 1999). One of the major benefits a combination of good biotechnology and good agronomy could bring is to prevent environmental damage from the conversion of fragile marginal lands into arable land, through instead increasing crop yields on existing land. The two studies by the Nuffield Council on Bioethics (1999, 2003) provide a detailed and balanced analysis.

The potential gains in productivity impacts of biotechnology will not necessarily be the same for developed and developing countries, as the scale of the farming operation (much smaller farms), management practices (lower mechanisation) and use of inputs (often much lower) are usually very different in developing countries. So it is dangerous to generalise potential impacts from developed to the developing countries. However, there remains the potential for GM technology to assist in efficiency increases, for example, by releasing labour from weed or pest spraying activities. It is clear that the rate of increase in area sown by developing country farmers is now exceeding that of developed country farmers. Improved seed is a relativelt easy technology to disseminate. In absolute number terms, there are also far more farmers producing GM crops in developing countries, too. By 2003, more than 5 Chinese million farmers adopted Bt cotton and nearly 60% of the cotton area was planted to GM varieties (Huang et al. 2003). Their survey data showed an average increase in yield of almost 10% and a decrease in pesticide use by 60%. Part of the reason for the government acceptance of GM cotton in China may be that GM varieties were developed in the public sector in parallel with importation of commercial varieties.

China has the largest plant biotechnology capacity outside the USA, and unlike the USA, the public sector has led its development. It was the first country in the world to adopt GM crops for routine farmer use (tobacco, 1992). Apart from cotton, tomato, sweet pepper and petunia, which have been approved for farmer use, a very large number of crops have been developed to the glasshouse stage. A significantly increased focus on biosafety over the last few years has delayed commercial release of GM rice and other food crops. Biosafety laws have been in force since March 2002 – these require imported GM grains to have official safety verification and be labelled. In the last couple of years, although there has been some community opposition, government attitudes in Philippines, India, Thailand and the Republic of South Africa have shifted to allow field trials of selected crops and in some cases, commercial production or import of GM crops. However, there is still some debate as to whether support of biotechnology – either by developing country governments or donors - has diverted investments from crop breeding and management and better water use that are more likely to have impact in the short term. A major constraint is that the development of policy settings in areas such as biosafety and food labelling did not keep pace with technical developments in developing (and developed) countries and that this has caused a delay in consideration of the release of GM crops. Such development is now required as a result of WTO/TRIPS obligations. The globalisation of the seed and life science industry has also proceeded faster than globalisation of regulatory systems. Bilateral trade issues and interactions with donors also can dominate decision making in developing countries. Input by farmers' groups is also less likely to be effective in influencing national policy, and the heavy involvement of international experts can also further disempower developing country policymakers.

Have the right applications been targeted for poor farmers ?

The main GM trait/crop combinations (herbicide resistance in soybean and yellow maize) widespread in North America are of limited relevance to most developing country farmers. This is not surprising given the aim of private sector research to recoup returns from large-scale farmers who can afford to pay for use of the resultant GM seeds. So with the exception of cotton, many of the key crops (such as rice, wheat, white maize, millet, sorghum, cassava, sweet potato, banana and yams) and traits for developing countries have been ignored thus far, although the public system in China has developed an impressive pipeline of GM crops at pre-release stage. As research capacity in a number of Asian countries grows so does the number of GM crops developed locally, and more of the current GM crops and traits targeted in current research are relevant than in the 1990s.

Some of the applications of biotechnology needed by developing countries include targets that are difficult to achieve through conventional plant breeding, such as:

- Increased crop productivity, either through direct increase in yield or crops with greater tolerance to stresses. This could be achieved through broadening tolerance to drought, flooding, salinity, heavy metals and other abiotic and biotic stresses and through improved water-use efficiency. Developing such crops is challenging as the characteristics are either usually controlled by many genes and/or the genes regulating the desired characteristic have not yet been identified.
- Increased crop quality, through improvements in postharvest and processing quality and storage life, and improved nutritional quality (increases in available Vitamin A, Fe, Zn, I, and lysine)
- Herbicide-resistance, to reduce labour costs in weed management and facilitate reduced tillage.

Technical advances likely to have impact in the short-to-medium term include drought-, heat- and salinity-tolerance in crops such as rice and tomatoes; increased available vitamin A in rice and oilseeds; new sources of virus resistance (e.g. sweet potatoes resistant to feathery mottle virus, papaya ringspot virus resistant papaya, peanut clump virus resistance); delayed ripening in tropical fruits to ease postharvest handling; crops which phytoremediate pollutants such as arsenic in contaminated soils; cottonseed oil that does not need hydrogenation for food use and several crops producing edible hepatitis vaccines. An up-to-date database of "Developing Country Biotechnology profiles" containing policies, regulations and research updates is provided at www.fao.org/biotech/ inventory_admin/dep/default.asp, while a recent study showed that 46 different crops are currently being engineered by developing country researchers (Atanassov et al. 2004). Large-scale field trials and commercial trials of GM crops have progressed in recent years in countries that formerly were reluctant to approve them, such as Thailand, the Philippines, India and Brazil.

However, challenges for the wider production of GM crops remain. Commercial plantings of GM cotton in Sulawesi in Indonesia were abandoned due to low returns, while poor protection of intellectual property for GM soybean in Argentina (widespread sales of "black market seed") led Monsanto to withdraw from this market in early 2004. Developing countries need to ensure that their investments in GM crop technology are based on "demand pull", by establishing situations where biotechnology has a comparative advantage in delivering varieties that conventional breeding cannot. Biotechnology R&D centres often require better integration with breeding and agronomy programs, and extension systems require strengthening to ensure improved varieties and technologies are disseminated. Are GM crops valid food aid ? In the recent African famine, US food aid was rejected by several countries, including Zimbabwe and Zambia since it contained GM maize grains. While it could be argued that this was a "precious" attitude to adopt in an emergency situation, the author argues that it is appropriate for donor countries to identify whether the grain is GM and to offer alternatives (non-GM or milled grain) where feasible. Respecting the right to choose of the recipient country is important as it is highly likely that some of the grain received for food would be planted. Food aid should not be responsible for the accidental introduction of GM crops. But the claim by some (www.seedsofdeception.com) that GM food aid was part of a plan by "corporations to control the food supply" seems somewhat hysterical.

The FAO "State of Food and Agriculture 2003-04" report explored the potential of agricultural biotechnology, especially GM crops, to meet the needs of the poor (www.fao.org). It concluded that agricultural biotechnology can help the poor by reducing reliance on toxic agrochemicals, lowering production costs, enhancing nutrition and improving disease control. These gains can boost agricultural productivity and reduce food prices. The report also presented an analysis of the socio-economic impacts of technological change in agriculture and surveys the current evidence regarding the safety of transgenic crops for human health and the environment. It recommends targeted investments in research, extension and regulatory capacity to ensure that the potential of agricultural biotechnology is brought to bear on the needs of the poor.

Are the overall environmental benefits of GM crops positive or negative ?
This remains an area of significant debate (FAO/WHO 2000). The environmental benefits of GM crops are possibly their most significant positive impact at present, but probably these have not been strongly enough publicised (Dale et al. 2002). Benefits include:

- significantly fewer insecticide applications (especially less endosulfan and pyrethroid applications in cotton). This has health benefits for the farmers and rural populations, potential for reduced contamination of water and soil and the development of increased populations of beneficial insects (Phipps and Park 2002)
- greater use of less persistent herbicides (although use of low-toxicity herbicides such as glyphosate may be increased). More importantly, use of herbicide-resistant crops also allows for wider employment of reduced tillage strategies, leading to conservation of soil structure and moisture (Fawcett and Towery 2003).

However, potential negative environmental effects of GM crops also provide a major source of opposition to their use. It is often claimed that "once a GM crop is released, unlike a drug it cannot be recalled". This is true only to a limited extent. Companies can be forced by governments to stop marketing a crop and new crop varieties supersede existing ones because of improved yield, disease resistance or quality at regular intervals. Environmental concerns relating to GM crops include:

- increased use of herbicides such as glyphosate (although these are of very low toxicity) and concern that older, more persistent herbicides would be needed to control adventitious GM canola
- selection for resistance to herbicides or BT- resistant insects (Shelton et al. 2002). In Australia and other jurisdictions there have been caps imposed on the total proportion of a GM crop within the total area of cotton grown to limit this possibility. The development of "double gene" varieties also reduces potential for resistance developing.
- effects on non-target species. In 2000 there was a controversy in the US over whether BT maize posed a threat to Monarch butterflies. However caterpillars were shown to have only limited sensitivity and had limited exposure to BT pollen under field conditions (Zangerl et al. 2001).
- the potential for negative impacts on agricultural biodiversity. This could arise if wide adoption led to the growing of monocultures of particular GM crops and a narrowing of varietal diversity.
- pollen or gene flow to other species, non-GM crops of the same species or to related species (Ellstrand et al. 1999; Bureau of Rural Sciences 2002). There is particular concern about transfer of genes for herbicide resistance to weed species. There is evidence that hybrids can form between canola and weedy brassicas (Lefol et al. 1995), and canola plants produce large numbers of seeds so a cross-pollination rate as low as 0.01% could result in significant transfer. Factors affecting the extent of possible gene flow include the type plant mating system (self- or cross-pollinated) and the probabilities of pollen transfer (pollen vectors, pollen amount, proximity of related species) and of hybrid formation (www.affa.gov/segregation). However, genes that do not confer a "fitness" advantage to wild relatives will be unlikely to be spread quickly. This means that each transgene and crop needs to be examined on a case-by-case basis (Burke and Rieseberg 2003).

The last issue is the most common one cited in the moratorium by Australian states on GM crops such as canola. On one hand, it is being promoted as an environmental "duty of care" under the precautionary principle, but others see the moratorium as depriving farmers of the freedom of choice and the ability to assess for themselves the potential value of the technology. Pollen drift was also considered responsible for the contamination of GM-free corn by Starlink® corn in the US. A range of technologies can be used or are under development to limit gene flow. These include isolation of related crop by use of different sowing times or physical isolation (including the use of barrier crops). A range of technical approaches are also under development, such as apomixis or use of male sterile plants, to prevent pollen transfer, gene flow or survival of hybrids. Use of chloroplast-specific vectors is another approach, since chloroplasts are inherited maternally and the chloroplast genes are thus not transferred in the pollen (Daniell et al. 1998).

GM crops – health hazard, health wonder or mostly irrelevant?
Some have claimed that a huge experiment has been underway with GM foods. Billions of meals of GM foods have consumed over the last decade without ill effects - most North Americans eat the products of GM crops at each meal. The Society of Toxicology (2002) concluded that "no verifiable evidence of adverse health effects of biotechnology-derived foods has been reported". However it was emphasised

that "methods have not yet been developed with which whole foods (in contrast to single chemical components) can be fully evaluated for safety". It is common practice to test the acute toxicity of new drug in experimental animals by administering a somewhat larger than standard dose. However, when a GM food forms a major part of a diet already, it is not possible to reasonably test the effects of increasing the level of the food in the diet by say, 10-fold. Some groups have expressed concerns about antibiotic resistance marker genes entering the food chain from GM crops, potentially leading to antibiotic resistance in people consuming them (www.choice.com.au). While there is no evidence for resistance developing in humans or experimental animals, in recent years there has been a move away from using antibiotic resistance marker genes in transgenic plants.

The potential for allergy problems certainly are real, along with the potential presence of toxins or anti-nutritional factors in GM crops. In early work, a high-sulfur gene from brazil nut was introduced into soybean and its protein product was an allergen. The crop was withdrawn before it reached the market. There are some reports that when Starlink® corn accidentally entered the food chain in 2000 it produced more allergic reactions, and there are some anecdotal reports of increased allergies from Roundup Ready® soybeans. Researchers and companies are aware of the need to thoroughly test the allergenicity of the protein product of any modified gene prior to its release in a GM crop. There are several approaches, ranging from prediction of potential allergenicity from the amino acid sequence of the encoded protein through to use of *in vitro* and *in vivo* assays.

There are at least four ways in which new GM crops can potentially have positive impacts on human health. The first is through inclusion of desirable nutritional characteristics, secondly, the plant expression of vaccines for cholera and other serious diseases (Arakawa 1998) and thirdly, work on removal of allergens from crops such as peanut. Finally, there is some evidence that BT corn may often contain lower levels of mycotoxins under poor storage conditions since the insect damage that increases susceptibility of corn to toxinigenic fungal infection is usually reduced. This could be quite important for developing countries.

Who really benefits economically – big business, farmers, or consumers?

Results on returns to these groups from commercialization of biotechnology in North America are summarized by Traxler (2004), and it is shown that economic returns have been shared between farmers, industry and consumers. There have been few obvious consumer quality benefits from the traits in the major crops commercialised thus far, although applications such as improved shelf life and nutritional benefits are at the trial stage. However, several of the economic modeling studies described above have shown that consumers have benefited through lower prices. One major difference between developed (especially those in Europe that oppose GM crops) and developing countries is that food forms a very small part of the household budget so the importance of lower food prices is lower.

Life science companies are certainly (and appropriately) in the GM crop business for profit, but profits are usually only realized after many years of investment in research. Many of the issues surrounding commercial involvement provide special challenges for developing countries. Most biotechnologies are privately owned, and there are often few incentives for companies to invest in the countries that may stand to benefit from the technologies the most. New approaches are needed to encourage greater private sector involvement in developing countries. Geographical market segmentation may allow developing country farmers to access biotechnology products under realistic conditions, and other market instruments may be needed to encourage further investment. Poor intellectual property protection in some countries is limiting investment by the private sector. The right of farmers to be able to choose between the production of GM and non-GM crops is also important for developing country farmers. This means on-going availability of open pollinated varieties – most likely produced through public research systems - that can be kept for farmer saved seed. However, experience has shown that smallholders will purchase hybrid seed if there is evidence of consistent yield advantages. With poor government agricultural extension systems in many developing countries, the private sector is assuming an increased role; the same trend is apparent in many developed countries, too. Some of the companies involved in GM crop marketing will suffer from their success in that markets for crop protection chemicals will shrink, in part from the wider use of herbicide-tolerant and insect resistant GM crops (www.klinegroup.com).

Trade implications

A number of studies (Anderson and Nielsen 2002; Foster et al. 2003) have attempted to model the impacts for trade returns of countries deciding to produce GM crops. As for all modelling exercises, the results depend strongly on the assumptions that are initially made. Some studies assume that there will be potentially higher export revenue from non-GM crops, others do not. While there have at times been market premiums for non-GM crops, there is not consistent evidence that this is usually the case (ERS, 2000). A second problem with many of the modelling studies is that they do not usually capture or value indirect impacts of crop choices on human health or the environment. Assuming that Western Europe will continue to maintain a poor acceptance level for GM crops, countries could adopt one of three policy approaches: adopting GM technology, produce only non-GM crops or to follow a market segregation approach (i.e. producing non-GM products for some markets and GM products for other markets, such as their own domestic market). Returns to the different approaches will depend on the size of potential gains in domestic consumption, changes in export income and costs of segregation and GM labelling. Different studies have modelled a range of scenarios, but many look at three options: all countries adopting GM technology, Europe remaining a non-adopter, and a third option which has a large number of countries not adopting GM crops. The models usually make assumptions of a flat percentage increase in productivity occurring in countries that adopt GM crops. Foster et al. (2003) showed that there would be substantial economic gains in gross national product in regions where GM technology is introduced (up to USD $210 billion annually if all countries adopt), and that impacts are greater (2.1 % of GNP) for the least developed countries than developed countries (0.2 % of GNP).

The Australian Government Productivity Commission (Stone 2002) modelled the impacts of uptake of GM technology in grains and oilseeds (other than wheat) on Australian trade, and found that wider adoption of GM technology would have little effect. Market shares could be lost if Australia continued to produce low levels of GM crops while trading partners continued the adoption of GM crops. Fewer economic studies on potential economic impacts have been commissioned in Europe, and those that have suggest that the benefits of the current generation of GM crops may be limited (e.g. for the UK, www.number10.gov.uk/output/Page4127.asp), and that future crops, for example, those offering health benefits to consumers may have a greater benefit flow.

Intellectual Property management – necessary for research and investment, or only a tool for the rich to get richer ?

Intellectual Property (IP) issues have a much greater impact on GM crop use than most other areas of agriculture. Images of farmers being prosecuted for using saved GM seed on their own farms (e.g. www.percyschmeiser.com) and of companies seeking IP protection for GM crop varieties that have pedigrees containing popular varieties used in developing countries, are being used as popular weapons by those groups opposed to GM technology. The fact that farmers can chose whether or not grow GM varieties is often underplayed, although constraints on farmers' ability to save proprietary seed could put them under some disadvantages, for example, in recovering from a natural disaster.

With GM crops, proprietary technologies relate to the protection of target genes for particular traits and protection of enabling technologies (gene regulation, selectable markers, promoters, transformation technologies). Developing countries need to pay attention to IP management for several reasons (Giannakas 2001). IP management of GM crops affects not only the "licensing in" of technology owned by developed countries, but also the "freedom to operate" with GM crops developed by that country. Least Developed Countries among World Trade Organisation members have until 2005 to make their IP regulations conform with TRIPS (Trade-Related Aspects of IP regulations). The challenge is that legislation not only needs to be passed but also implemented and policed. It has often been stated that developing countries with effective IP regimes may attract more foreign investment for GM crop research, although evidence for this is mixed. They certainly will be more attractive markets for commercial GM crops. But are current IP management processes an imposition for developing countries? They are largely based on Western and multinational company concepts of property rights and law, and are costly to implement so could disadvantage poor countries. Some have argued that changes to Western patent policy are needed (Taylor and Catford 2003) or at least to assist developing countries to strengthen their bargaining positions (Byerlee and Fischer 2001).

Labelling and Segregation – consumer right to choose or unworkable apartheid ?

Food and commodity labelling - a right or an impost ?

Different approaches have emerged in different countries, largely reflecting their national attitudes towards adoption of GM crops. Codex Alimentarius recommendations for food labelling do exist, but countries are "doing their own thing". In Australia, the labelling rules are seen by many to reflect a pragmatic approach, relating to the final product and not the process by which it has been manufactured. GM foods need only be labelled if there is novel DNA and/or protein present in the food above 1% (or 0.1% as flavours), or the food has altered characteristics from the non-GM food (e.g. oil content, allergens, components possibly of concern to particular religions). Meat, eggs and dairy products made from animals fed with GM stockfeed, highly-refined food components that have been derived from GM crops (such as oils, sugars, starches), food prepared at point of sale (e.g. restaurants), processing aids using GM microbes and foods unintentionally contaminated by up to 1% are exempt from labelling. In the USA, labelling has only been needed if the modification introduces an allergen or substantially changes the food's nutritional composition. In Europe, all foods derived from a GM source must be labelled, irrespective of whether DNA or protein is present.

The trend for requiring the labelling of GM foods should be seen as part of a worldwide trend by consumers for greater information on the foods they consume. For example, many countries now require reasonably detailed food composition and nutritional data to appear on packages of all processed foods. However, in the absence of evidence of GM foods having negative health effects, does labelling of GM foods give inappropriate importance to something that is not a genuine health issue? On the other hand, few people dispute the appropriateness of halal labels in Muslim countries, and this is also a matter of personal conviction rather than health. Some studies suggest that labelling (and segregation) costs could reduce or even negate gains from GM crop development and will encourage food manufacturers to seek out non-GM raw materials and supermarket customers non-GM foods. This seems to be the experience from studies done in the US (Carter and Gruere 2003), and some have argued for voluntary labelling of premium non-GM products instead. The possible effect of labelling on sales is unclear. Some consumer and NGO groups have produced consumer guides for purchasing non-GM foods (e.g. Greenpeace 2003).

Segregation and co-existence

In systems that allow GM foods, different approaches are emerging to enable traceability of GM crops (Bullock and Desquilbet 2002). Segregation systems have been in place for grains in many countries for several decades as value can be created and preserved if grains of differing end-use qualities (e.g. higher protein bread-making wheat versus feed wheat) are binned separately. However, these systems do not require high levels of precision and there are a number of low-cost systems such as near-infrared analysis for protein content that can rapidly test that binning has been carried out appropriately. Traceability refers to mechanisms that enable the retrieval of information as to the history of a product or ingredient at any point in the food and feed chain, requiring systems of record keeping and documentation that enable tracking. Identity preservation is considered to be a more active process than traceability. Identity preservation systems require formal documentation to guarantee that GM and non-GM grain have been grown, harvested and maintained separately throughout the whole supply chain. In Australia, an industry alliance has developed a detailed model for co-existence of production and supply chains (Gene Technology Grains Committee 2003), and segregation costs of an additional 15% of the value of the grain have been estimated.

Those who do not see segregation systems as workable have three main objections. Firstly, it is claimed that cross-contamination in the harvesting and transport of bulk grain commodities is inevitable, and secondly, that much of the cost of segregation will be borne by non-GM producers. (This cost will be able to be recouped if there are significant premiums for the non-GM product, but the experience thus far for such premiums is mixed). Many industry groups claim that it is not feasible to target these costs to GM producers, but on the other hand, there is some sympathy with the argument from those farmer groups that have always grown non-GM crops and want to continue to do so that it is unfair for them to absorb the additional costs of these systems. With labelling, it is almost certainly the non-GM producers that have to bear the costs of certifying that the food products are genuinely non-GM. Most studies conclude that the major costs of non-GM identity preservation and segregation depend on the tolerance levels set, either by government regulation or market requirement (Lin 2002). In the case of GM products, complexity comes with the issue of ‘unintended presence’. In the future if GM crops with high-value output traits (higher nutritional value of better processing quality) are commercialised, there may be strong incentives for the producers and marketers of the GM crops to cover costs of segregation. Thirdly, there are some concerns that segregation will not be policed. In China, labelling of GM foods was mandated from early 2002. However, there are a number of problems (Jia et al. 2003); no threshold for GM content above which foods require labelling was mandated; tests for detection of GM content are expensive or unavailable in China, and companies may intentionally fail to label foods over fears of loss of market share. There has been an explosion of commercial test kits and testing services for GM products triggered by Starlink® corn contamination of non-GM corn in the USA.

Can regulatory systems evolve that can please everyone ?

Regulatory systems must be flexible, to either allow increased scrutiny or relaxation of controls on particular GM crops based on the scientific evidence that emerges. It may be simpler and less expensive to embed biosafety regulation within existing institutions rather than build new ones, and in many countries collaboration between quarantine/ regulatory officials and environment policy makers should be strengthened. While it is imperative that individual crop/trait combinations be assessed on a case-by-case basis, harmonisation of regulations between countries is important. Costs could be reduced by sharing of methods and results, especially for similar ecological environments. Establishment of such systems for developing countries is a challenge, both because of the investment in capacity building and infrastructure that is first required but also because data on the ecological impact of some relevant GM crops under tropical or smallholder conditions may be incomplete. These countries can use internationally established guidelines such as those of the Codex Commission as a reference point. A number of donors have launched large initiatives to strengthen capacity in regulatory legal and technical skills, such as FAO and UNEP Global Environment Facility.

In Australia, the Office of the Gene Technology Regulator regulates the production, import or use of GM organisms for research or commercial purposes. Locations of GM field trial sites are usually disclosed, although in some cases this has led to their damage by activist groups. GM foods are regulated by Food Standards Australia New Zealand, who carry out pre-market safety assessment and establish mandatory labelling requirements. The principle is one of scientific, risk-based assessment. There are concerns by some consumer groups, including the Australian Consumers' Association, that the Australian regulators are not adequately investigating potential risks to health or the environment, particularly because the research data to support approval is developed by companies who have an interest in releasing the crop. But the system of provision of data by a company and review by an independent Government regulator is no different than that for the registration of agrochemicals or pharmaceuticals, and it would be unrealistic for the public sector to bear the cost of all trials.

Is it possible not to take sides - why is there so much opposition?

The public awareness program for GM crops was (usually) not handled well by scientists and life science companies in the years following the release of the first GM crops, and in some quarters awareness programs remain poorly implemented. There was often a failure to recognise that there had been a loss in the overwhelming faith in corporations and government regulator that had been present in the post World War 2 decades. Attitudes even changed after the release of some GM foods – in the mid-1990s British companies proudly labelled canned tomatoes as having been genetically modified, only to find that 3 years later many UK supermarkets had withdrawn GM foods from their shelves even though they initially sold well.

The opposition to GM crops is confusing to many scientists, who through their training, use reason rather than perceptions to come to conclusions and thus in some cases can be dismissive of social process and perceptions. In the face of bans on GM crops, the lack of any significant opposition to the increasing use GM drugs such as cloned insulin is indeed illogical! The huge popular and scientific literature on GM crops is usually polarized with often only one side of "the argument" presented (Skerritt 2000). There is no doubt that "fear of the unknown" is a major tool used by anti-GM crop groups. Many companies recognise that they often did not communicate well with the public in the past and a number of communication initiatives have been formed. The donation of technologies, genes and markers to developing countries has increased. Farmer organisations have become more active; most are pro-GM crops, promoting the co-existence of GM and non-GM supply chains (e.g. in Australia, the National Farmers' Federation, www.nff.org.au/pages/sub/biotechnology_position.pdf). But some farm industry groups are advocating moratoria on the commercial expansion of GM crops because they are concerned about loss of export markets (through concern about consumer acceptance).

A survey project conducted in 2000/01, "Public perceptions of agricultural biotechnologies in Europe" (www.pabe.net) showed that many commercial and scientific groups misunderstood the public responses to GM crops. They thought that they are due to a lack of technical information about GM crops, and that media misinformation is a major problem. They also believed that the public wrongly thinks that GM crops are unnatural and unreasonably demand zero risk but no longer trust food regulators. Focus groups suggested that public concerns related more to a view that clear benefits of GM foods to consumers have not been shown and that the public should have been better informed before the arrival of GM foods on the market. They are concerned whether regulatory authorities can really be effective and are unclear who will be responsible if unforseen impacts occur.

GM foods: do consumers love them or hate them ? Are attitudes softening?
There is by now quite a large consumer survey literature on GM crops. Like most surveys they have usually not been carried out by disinterested parties – so the way the questions are asked and the results obtained often reflect an initial bias. For example, when Northern Irish consumers were asked whether they would prefer GM blight resistant potatoes over sprayed conventional potatoes, the response was evenly divided (news.bbc.co.uk/1/hi/northern_ireland /3093837.stm). In Australia, a recent survey showed (www.biotechnology.gov.au) that 56 % of respondents stated that our farmers needed gene technology to remain competitive, although only 45 % said they would eat GM foods. If foods are modified for health and nutrition benefits then the potential for support appears much greater than for traits that benefit farm incomes. However, even in the absence of direct consumer benefits there seems to be quite strong support across a number of countries for the use of pest- and herbicide-resistant GM crops because of the perceived environmental benefits (ERS, 2001). A more useful approach may be to conduct surveys that compare concerns over GM foods to other prevalent food safety concerns (Owen et al 2001).

Biotechnology Australia (2003) and ERS (2000) have summarized the results of many international surveys. In Australia, support for GM crops in the early 1990s turned to negativity in the mid 1990s, although in the last few years there are equal numbers of people supporting and opposing. A majority of US people interviewed supported GM crops and the support has either been unchanged or weakened slightly over the last decade. Surveys by the Asian Food Information Center (www.afic.org) showed that two-thirds of surveyed consumers in China, Thailand, and the Philippines believed that they would benefit from GM foods. The International Council of Sciences (Persley 2003) has taken a constructive approach of summarising areas of scientific convergence and divergence and listing gaps in knowledge on major issues surrounding GM crops.

Unnatural and immoral – ethical issues
Ethical concerns are typically individual concerns for which “right and wrong answers” may not exist. One group of concerns about GM foods relate to the creation of life forms that do not exist in nature. However, many crops and species such as triticale that have been cultivated for many years also do not exist in nature. Another concern relates to opposition to commercial protection of lifeforms or of “building blocks” such as genes. However, the corporatisation of agriculture is happening anyway. In developed countries, scale, intensification and business principles are required to maintain productivity, while developing country farmers who are able to obtain and maintain cash incomes are more able to withstand drought, conflict and other disasters and provide for health and education for their families. Some of the groups opposed to GM technology have expressed concerns that the additional genes inserted into the plant genome could interact with the plant’s own genes in unpredictable ways, changing the expression of the plant genes. Some of the early (and in retrospect, unfortunate) hype around GM plant technology involved demonstrations that genes from animal sources could be expressed in plants. With the exception of genes encoding antibodies, vaccines and pharmaceuticals, reasonably widespread community unease has limited earlier plans to develop and release commercial food crops expressing animal genes.

What do the churches think ? Different religions and different groups within the major religions have divergent views. While all possibly would agree with the statement “Respect for life created by God has priority over what is technically feasible” (Protestant Regional Churches of Germany and Roman

Catholic Dioceses of Germany, October 2003) although it was used to argue against the development of GM crops, the Vatican's view is rather balanced (Vatican, 2001). Several Muslim groups have given tacit approval to foods from GM crops, as long as they do not contain pork genes or products. These include the Indonesian Ulemas Council (straitstimes.asia1.com.sg/asia/story/0.4386,198597-1057701540,00.html) and the Institute of Islamic Understanding in Malaysia (www.bic.org.my). But groups such as the Catholic Institute for International Relations (www.ciir.org) oppose promotion of GM crops in developing countries and the South African Council of Churches opposes importation of GM crops.

Conclusion: Hype or hope? Has the technology been oversold? Is universal adoption inevitable?
Good technology is not enough. The story of the development of nuclear power to generate electricity over the last 50 years may have some useful lessons for GM crops. Nuclear energy is several thousand times more efficient in terms of fuel mass to energy ratio than any other current energy source. Currently, about one-sixth of the world's electricity is generated by nuclear reactors. If this electricity were to be generated from coal, over one billion tonnes of coal would have to be burnt, with the corresponding increase in production of greenhouse gases and pollutants. In this sense, nuclear energy is much cleaner, and in many cases cheaper to produce.

Many nuclear power stations were commissioned in the 1960s and 1970s, but comparatively few in the decades after. Issues such as the problem of disposal of radioactive waste from reactors, and the risk of catastrophe from accidents (eg Three Mile Island in 1979 and Chernobyl in 1986) or as potential terrorist targets made a number of governments reluctant to invest in new power plants. For example, the UK energy white paper in 2003 proposed that no new nuclear power stations be built in the UK. With many of the original power stations are now reaching the end of their planned lives, this will mean that by 2020 only 5% of the UK's power will be generated from nuclear sources. However, like with GM crops, the plans responses of different countries to nuclear energy has differed. Those with little access to cheap alternative sources of power and with less intense community opposition, such as South Korea continue to construct new nuclear power stations. Similarly, it is not unlikely that less developed countries with a greater demand for efficient food, fibre and renewable material production will lead the world in the extent of production of GM crops in the future. The two potential lessons for GM crop technology are that it does not follow that just by having a more efficient technology it will be automatically accepted (a factor often forgotten by researchers !) and that quite different public policy approaches are likely be adopted over the long term by different governments. However, the analogy has its limitations. GM crop technology is different from nuclear technology in that it is not a potential tool for terrorists and is simpler – GM traits are inherited in a Mendelian fashion.

The pace of technology development and investment is not always as fast as we are led to believe. A clear memory of mine from the euphoria of the first manned lunar landing in 1969 was the bold statement that by 2000 such travel would be routine, and that communities of humans would be living on the Moon. In 1988, I also recall an eminent scientist predicting confidently that he expected the majority of Australia's wheat crop to be GM in 15 years time. Of course, neither technological change has happened thus far – technologies sometimes develop more slowly than anticipated, more importantly, public policy and commercial considerations can dominate. At the time of writing, Monsanto had just announced that it would abandon its plans to introduce GM wheat, although its trials of the herbicide-tolerant wheat had demonstrated yield improvements. This was because of potential resistance from major US and Canadian wheat export markets in Europe and Japan and the greater possibility of admixture of GM and non-GM wheats compared with crops such as fruit. Whether this reflects one company's decision about one crop or triggers a wider brake on the adoption of the GM crop technology in Australia and other countries remains to be seen.

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References

Abdalla A, Berry P, Connell P, Tran QT and Buetre B (2003) Agricultural Biotechnology – potential for use in developing countries. Australian Bureau of Agricultural and Resource Economics eReport 03.17, Canberra, Australia www.abareeconomics.com.

Agrifood Awareness Australia (2004) Global GM Food labeling laws. Biotech Bulletin No. 8. www.afaa.com.au/biotechpdf/08_2004_Global_Labelling_Laws.pdf

Altieri MA and Rosset P (1999) Ten reasons why biotechnology will not ensure food security, protect the environment and reduce poverty in the developing world. AgBioforum 2, 155-162 www.agbioforum.org

Anderson K and Nielsen C (2002) Economic effects of Agricultural Biotechnology Research in the presence of price-distorting policies. Discussion paper 0232, Centre for International Economic Studies, University of Adelaide, Australia

Arakawa T (1998) Efficacy of a food plant-based oral cholera toxin B subunit vaccine. Nature Biotechnology 16, 292-297

Asian Development Bank (2001) Agricultural Biotechnology, Poverty Reduction and Food Security, ADB, Manila, The Philippines

Atanassov A, Bahieldin A, Brink J et al. (2004) To reach the poor – results from the ISNAR-IFPRI next harvest survey on genetically modified crops, public research and policy implications, EPTD Discussion paper No. 116, International Food Policy Research Institute, Washington, DC, USA.

Brookes G and Barfoot P (2003) GM rice: Will this lead the way global acceptance of GM crop technology ? ISAAA Briefs No 28, ISAAA Ithaca, NY.

Brookes G and Barfoot P (2004) GM crops in Europe – reality or myth ? PG Economics, Dorchester, UK. www.bioportfolio.com/pgeconomics/GM_EUROPE_2/htm

Biotechnology Australia (2003) Biotechnology public awareness survey. Final report. manipulation www.biotechnology.gov.au/library/content_library/BA_MB2003_Final_public.pdf

Bullock DS and Desquilbet M (2002) The economics of non-GMO segregation and identity preservation. Food Policy 27, 81-99

Bureau of Rural Sciences (2002) Gene flow study: implications for the release of genetically-modified crops in Australia. www.affa.gov.au/corporate_docs/publications/pdf/innovation/Gene_flow_report.pdf

Burke JM and Rieseberg LH (2003) Fitness effects of transgenic disease resistance in sunflowers. Science 300, 1250

Byerlee D and Fischer K (2001) Accessing modern science: policy and institutional options for agricultural biotechnology in developing countries. IP Strategy Today, 1, 1-27

Carpenter J and Gianessi L (2001) Agricultural Biotechnology: Updated benefit estimates, National Centre for Food and Agricultural Policy, January.

Carter CA and Gruere GP (2003) "Mandatory labeling of genetically-modified foods: does it really provide consumer choice ?" www.agbioforum.org/v6n12/v6n12a13-carter.htm

Chassy B (2002) Food safety evaluation of crops produced through biotechnology. Journal of the American College of Nutrition 21, 166S-173S

Codex Alimentarius Commission (2001) Principles for the Risk Analysis of Foods derived from Biotechnology, www.codexalimentarius.net/biotech/en/ra_fbt.htm

Dale P, Clarke B and Fontes EMG (2002) Potential for the environmental impact of transgenic crops. Nature Biotechnology, 20, 567-573.

Daniell H, Datta R, Varma S, Gray S and Lee SB (1998) Containment of herbicide resistance through genetic engineering of the chloroplast genome. Nature Biotechnology 16, 345-348.

Ellstrand NC, Prentice HC and Hancock J (1999) Gene flow and introgression from domesticated plants into their wild relatives. Annual Review of Ecological Systems 30, 539-563.

ERS (USDA Economic Research Service) (2000) Biotechnology: US grain handlers look ahead, Agricultural Outlook, Special Article, April 2000.

ERS (USDA Economic Research Service) (2001) Impacts of adopting genetically engineered crops in the United States, ERS Research report, www.biotech-info.net/adopting-impacts.html

Fawcett R and Towery D (2003) Conservation tillage and plant biotechnology: how new technologies can improve the environment by reducing the need to plow, Conservation Technology Information Center, West Lafayette, IN, USA. www.ctic.purdue.edu

FAO/WHO (2000) Safety aspects of genetically modified foods of plant origin, Report of a Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology, 29 May - 2 June 2000.

Foster M (2003) GM canola. What are its economics under Australian conditions? Australian Grains Industry report, www.abareconomics.com

Foster M, Berry P and Hogan J (2003) Market Access Issues for GM products: Implications for Australia. Australian Bureau of Agricultural and Resource Economics, Canberra, publication 12559, 67 pp

Furtan H and Holzman J (2001) Agronomic costs and benefits of GMO crops: what do we know? In "Transforming Agriculture: the benefits and costs of genetically-modified crops", pp 47-58, University of Saskatchewan, Saskatoon,

Gene Technology Grains Committee (2003) Canola Industry Stewardship Principles, Avcare, Canberra, Australia.

Gene Technology Task Force (2002) Agricultural Biotechnology: Herbicide Tolerant Crops in Australia. Bureau of Rural Sciences, Canberra, www.affa.gov.au/content/output.cfm?objectID=4BEECF75-993E-48F7-A2F7_A26AA2BE5C964B80

Gianessi LP, Silvers CS, Sankula S and Carpenter JE (2002) Plant Biotechnology: Current and potential impact for improving pest management in US agriculture. National Center for Food and Agricultural Policy, www.ncafp.org

Giannakas K (2001) The economics of intellectual property rights under imperfect enforcement: developing countries, biotechnology and the TRIPS agreement. EPTD Discussion paper 80, International Food Policy Research Institute, Washington, DC USA.

Greenpeace (2003) True Food Guide: How to shop GE-free, 2nd Edn, www.truefood.org.au

Huang J, Rozelle S, Pray C and Wang Q (2002) Plant biotechnology in China, Science 295, 674-676.

Huang J, Hu R, Fan C, Pray E and Rozelle S (2003) Bt cotton: benefits, costs and impacts in China, AgBioForum 5, 1-14.

Jaffe G (2004) Regulating transgenic crops: a comparative analysis of different regulatory processes. Transgenic Research 13, 5-19

James C (2003) Global Status of Commercialized Transgenic crops: 2003. ISAAA Briefs, No 30, International Service for the Acquisition of Agrobiotech Applications; Ithaca NY 25 pp.

Jia, Hepeng (2003) GM labelleing in China beset by problems. Nature Biotechnology 21, 835-836

Leading Dog Consulting and Synecon Pty Ltd (2003) A Review of Genetically Modified Canola Issues and Potential Market Impacts for the Australian Canola Industry, report for Avcare, Canberra, Australia.

Lefol E, Danielou V, Darmency H, Boucher F, Mallet J and Renard M (1995). Gene dispersal from transgenic crops. 1. Growth of interspecific hybrids between canola and the wild hoary mustard. Journal of Applied Ecology 32, 803-808.

Lin W (2002) Estimating the costs of segregation for non-biotech maize and soybeans. In "Market development for genetically modified foods" (Eds. V Santaniello, RE Evenson and D Zilberman), CABI Publishing, Wallingford, UK.

Losey JE, Rayor LS and Carter ME (1999) Transgenic pollen harms monarch larvae, Nature 399, 214

Marra MC, Pardey PG and Alston JM (2002) The payoffs to transgenic field crops: an assessment of the evidence. Agbioforum 5 (2), 43-50

Norton R (2003) Conservation farming systems and canola, The University of Melbourne, www.avcare.org/documents/Avcare%2026.03.03.pdf

Nuffield Council on Bioethics (1999) Genetically Modified Crops: the ethical and social issues. Nuffield Council on Bioethics. www.nuffield.bioethics.org/publications/pp_000000009.asp

Nuffield Council on Bioethics (2003) The use of genetically modified crops in developing countries: a follow-up discussion paper. www.nuffield.bioethics.org/publications/pp_0000000017.asp

OECD 2000. Report of the Task Force for the Safety of Novel Foods and Feeds, www.oecd.org/document/63/0%2C2340%Cen_2649_34381_1905919_1_1_1_1%2C00.html

Owen K, Louviere J and Clark J (2001) The potential impact on agricultural producers of responses to genetically modified products. Rural Industries Research and Development Corporation, US-92A, www.rirdc.gov.au

Persley GJ (Ed) (2003) New genetics, food and agriculture: scientific discoveries – societal dilemmas, International Council of Sciences www.icsu.org

Persley GJ and Doyle JJ (2001). Biotechnology for Developing Country Agriculture: Problems and Opportunities. In: “The Unfinished Agenda: Perspectives on Overcoming Hunger, Poverty and Environmental Degradation”. pp. 239-243. (Eds. Pinstrup-Andersen, P. and Pandya-Lorch, R). International Food Policy Research Institute, Washington, DC, USA.

Phipps RH and Park JR (2002) Environmental benefits of genetically modified crops; global and European perspectives on their ability to reduce pesticide use. Journal of Animal Feed Science 11, 1-18.

Plant Health Australia (2002) National Weeds Workshop: Workshop proceedings, 19-20 February

www.planthealthaustralia.com.au/project_documents/uploads/Weeds_workshop_proceedings.pdf

Pray C, Huang J, Hu R and Rozelle S (2002) Five years of Bt cotton in China: the benefits continue. The Plant Journal 31, 423-430.

Rieger MA, Lamond M, Preston C, Powles SB and Roush RT (2002) Pollen mediated movement of herbicide resistance between commercial canola fields. Science 296, 2386-2388

Serageldin I and Persley GJ. Eds (2000). Promethean Science: Agricultural Biotechnology, the Environment and the Poor. Consultative Group on International Agricultural Research, Washington DC, USA.

Shelton AM, Zhao J –Z and Roush RT (2002) Economic, ecological, food safety and social consequences of the deployment of Bt transgenic plants. Annual Review of Entomology 47, 845-881

Skerritt JH (2000) Genetically-modified plants: developing countries and the public acceptance debate, AgBiotechNet, 2, February, 1–8.

Skerritt JH (2001) Biotechnology policies for Asia: Current activities and future options, pp 251-271.in "The Future of Food: Biotechnology markets and policies in an international setting" (Ed. PG Pardey), International Food Policy Research Institute, Monograph Series, Washington, DC, USA.

US Society of Toxicology 2002. The Safety of Genetically Modified Foods Produced Through Biotechnology, Society of Toxicology Position Paper, www.toxicology.org/information/GovernmentMedia/GM-Food.html

Stone S, Matysek A and Dolling A (2002) Modelling possible impacts of GM crops on Australian trade. Productivity Commission Staff research paper, Melbourne, October www.pc,gov.au

Taylor MR and Catford J (2003) American patent policy, biotechnology and African agriculture: the case for policy change. Resources for the Future Report, November, www.rff.org

Traxler G (2004) The GMO experience in North and South America – where to from here ? Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, September 2004, in press.

Vatican (2001) Science and the future of mankind: Science for man and man for science. The Pontifical Academy of Sciences, Rome, Italy

Zangerl AR, McKenna D, Wraight CL, Carroll M, Ficarello P, Warner R and Berenbaum MR (2001) Effects of exposure to event 176 *Bacillus thuringiensis* corn pollen on monarch and black swallowtail caterpillars under field conditions. Proceedings of the National Academy of Sciences, 98, 11908-11912