Development, release and regulation of GM crops

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In 1996, genetically modified (GM) crops occupied 2.8 million hectares worldwide, and in 1997, 12.8 million hectares (Fig.1). The increase largely reflects the availability of new products, and these products are clearly popular. What benefits do they offer? Their proponents claim that they are a contribution towards a more sustainable agriculture, while the cynics say that they are being developed to provide greater profits for a few commercial companies. There is some truth in both views, and it is important that there should be open debate about the pros and cons of GM crops and about the ways in which they can most safely and effectively be deployed.

Figure 1 Oilseed rape: the GM crop furthest towards commercialization in the UK.

There is no doubt that GM crops can contribute to sustainability by reducing inputs of agrochemicals. For example, insect-resistant GM cotton occupied only about 13% of the US cotton acreage in 1996, but is estimated to have eliminated the use of approximately 250,000 gallons of insecticide. At first sight, it seems likely that this reduction in insecticide usage will also have had a beneficial impact on biodiversity, but it is too soon to tell whether this is borne out in practice. Indeed, it is worth noting that there is an inherent tension between sustainability and biodiversity, because if the diversity of pest, disease and weed species is maintained, inputs that control them are going to be needed in any successful agriculture.

Many people fear that the novel technology involved in GM crops will have unexpected effects on health or on the environment. On health, it is important to distinguish between possible effects of the crops themselves, for example in the form of allergies, and the safety of foods derived from those crops. In the environment, it is feared that we may be creating monster plants or 'superweeds'. However, given the many years of study that go into the development of any GM crop plant, they are much less likely to prove monstrous than alien plants that can be introduced quite casually. It is hard to imagine a GM crop plant becoming as much a problem as giant hogweed, Japanese knotweed or *Rhododendron ponticum* have been in Britain. The best answer to the fear of unexpected effects is to point out that the technology is better understood and more predictable than many people think. Globally, there have been about 25,000 field trials, i.e. experiments in the open field, which have provided a vast amount of observations and data on GM crop plants and risks that might be associated with them.

Some people have ethical objections to GM plants, or more often to foodstuffs derived from them. Everyone, including scientists, has moral views and concerns, many of which we hold without really knowing why: for example because of upbringing or the influence of friends and family. Ethics describes the more philosophical process by which a group, a community, or a society decides how to scrutinise its moral beliefs and develop standards by which to regulate future actions or behaviour. Because genetic manipulation requires premeditated, skilled and, to the layman, poorly understood processes, albeit involving extremely minor alterations to the genetic material of an individual organism, it raises individual, group and public concerns about immediate or long-term effects, the speed of change, and society's view on living matter as a commodity or human construct. There are some for whom firm intrinsic beliefs (moral codes) dictate that certain scientific or technological advances and applications are wrong. Yet, they may drive a car, fly in a plane or accept modern medicines (many of which are products of genetic engineering). For others, a more analytical cost-benefit approach is required. What are the detrimental versus the beneficial consequences of a given technology? Is it consistent to denounce certain developments while

accepting and benefitting from others? Where these concerns are based on sound information and deeply held conviction, they must be respected.

At a practical level, GM technology is, if anything, more precise and predictable than all the methods which humankind has applied in selective breeding for domestication of food crops and companion or farmed animals over 10,000 years. Moreover, releases of all GM plants are very heavily regulated, at least in the UK and Europe. The aim of this article is to describe how GM crops are developed and released, how they are regulated, and the ways in which these processes interact with one another. The perspective is as seen from SCRI, under the UK regulatory regime, with examples drawn where possible from our own work.

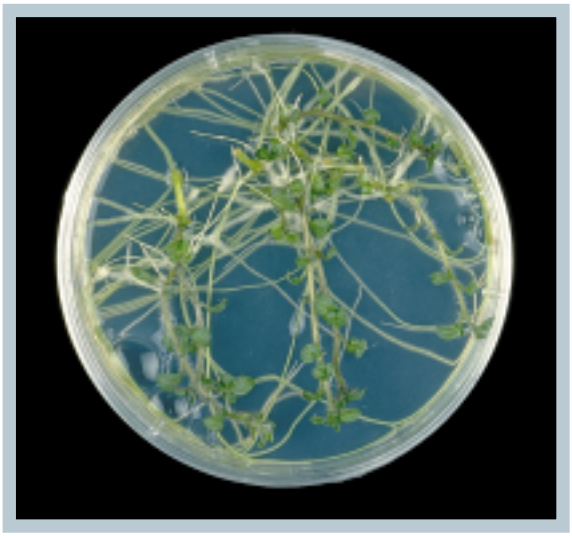

Figure 2 One of the first steps in production of a GM plant involves selection of transformed cells in tissue culture and their regeneration into whole plants.

What is a GMO? Genetic modification is defined as the insertion into an organism, either by means of a natural vector (e.g. *Agrobacterium*) or otherwise (e.g. by particle gun bombardment), of heritable genetic material (i.e. DNA) prepared outside the organism. It also includes protoplast or cell fusion when the parents are plants from different botanical families, but not when they are from the same family. It does not include techniques such as mutagenesis or manipulation of ploidy unless the starting material has previously been genetically modified. A genetically modified organism (GMO) is an organism that has been produced by genetic modification as defined above, or an organism containing genetic material derived or inherited from such a modified organism. Thus, in addition to the original modified plant, any progeny plants derived from it through seed or vegetative propagation, or crosses bred from it, are considered to be GMOs.

Development of GM plants in containment The appearance of a GM crop on the market is the culmination of a long process of development. Much work is done under conditions of containment in laboratories, growth cabinets, glasshouses and plastic tunnels. This phase includes development of the methodology required to transform the plant species in question (Fig. 2), and experiments designed to test whether the genetic constructs really do what they are designed to do. Experiments at this stage often involve model systems; for example, constructs designed to be used in potatoes may first be tested in tobacco (both are members of the family *Solanaceae*), because the experiments can be done more quickly and easily. It should also be remembered that GM plants are valuable research tools in their own right, and many experiments in containment are using them to investigate something else. Thus, it should not be assumed that every GM plant that scientists produce is the precursor of a product intended for the marketplace.

The key element in the regulation of experiments with GMOs in containment is risk assessment. Even before starting the work, the scientists have to assess what risks the experiments they are proposing to do might pose to their health or that of their colleagues or members of the general public, and what risks there might be of harm to the environment. One difficulty here is in defining what constitutes harm to the environment. A major effect, such as the extinction of a species, is obviously harmful, but where the likely effects are small, there is no clear baseline for comparison in deciding whether they are harmful. For example, in considering whether a GM insect-resistant crop is harmful to non-pest species, the obvious comparison is with the effects of the pesticides that would be used on a conventional crop. However, agriculture itself is artificial, and the decisions to cultivate the land, and to grow one crop rather than another or to put the field into set-aside have very large effects on the insect fauna.

Methods of Risk Assessment The first step in risk assessment is identification of hazards, which are characteristics of the GMO that could give rise to harm. This involves imagining the possible scenarios both of what the experimenters expect to happen, and of the plausible alternatives, including what might go wrong. Subsequent stages of risk assessment involve estimat-

ing the likelihood of the harm occurring and the magnitude of harm if it did occur, for each of the hazards that has been identified, and bearing in mind the conditions under which the experiment will be done. It is essential to remain open-minded at the stage of hazard identification, and not to discard any possibilities prematurely because they are unlikely or inconsequential. In this way, the written record of the risk assessment will show the reasons why some risks have been discounted. It is generally impossible to quantify risks in numerical terms, and resort is had to terms like 'high', 'medium', 'low', 'negligible' and 'effectively zero'. Finally, an overall risk for the experiment is estimated, which is usually equal to the greatest of the individual risks arising from the list of hazards. If the assessment shows that there is any significant risk, it indicates that the containment conditions need to be tightened up so as to eliminate that risk or, if that is not possible, that the experiment should not be done at all. For example, consider a GM swede plant, modified by insertion of a gene for resistance to fungal attack, perhaps aimed at improving the storability of the swedes. One of the hazards that would be identified would be the escape of pollen of the GM swede, which could fertilize not only swedes but also any oil seed rape that might be flowering nearby. Seed produced from such a fertilization event would carry the fungal resistance gene, and if this was expressed in the seeds themselves, it might make them less susceptible to fungal attack, more long-lived in the soil, and consequently even more of a weed problem than rape is at present. In the absence of any data indicating the contrary, it would have to be assumed that such a scenario is possible, and the potential harm to the environment would have to be assessed at least as 'moderate'. It would therefore be important to minimize the likelihood of such events occurring. One way of doing this would be to prevent the GM swedes from flowering, and in many experimental situations this would be acceptable. But at some stage, it would probably be necessary to produce seed from the plants for future propagation. This would need to be done under conditions of high security, outside the main flowering season for rape. However, it is not possible to choose a time of year when it can be guaranteed that no feral rape is in flower, so the escape of pollen from the swede flowers would have to be prevented by containing them within bags, as is done by breeders to achieve controlled self pollinations.

The Institute is legally required to have a Committee (the GM Safety Committee) to advise on these risk assessments. In practice, this means that the scientists who propose to do each GM experiment have to satisfy a representative selection of their colleagues that they have not neglected or underestimated any potential risk. It also ensures that each proposal is examined by scientists with a wide range of different kinds of expertise.

Collection of data on risk The risk assessment will often highlight areas where the magnitude of harm that the GMO might cause in the environment is uncertain. In such cases, the worst-case scenario has to be assumed, and rigorous measures to prevent escape of the GMO into the environment may be required. Meanwhile, further experiments may be planned to clarify the uncertainties about the potential harm. Such experiments will allow the risk assessment to be revised and may generate important data to support a subsequent proposal deliberately to release the GMO. For example, with plants genetically engineered to resist attack by insect pests (e.g. by expressing anti-insect toxins; Fig. 3), it may be unknown whether the modifications have any effects on non-target insects, especially beneficial natural enemies of pests. Recent studies at SCRI and the Swiss Federal Research Station for Agroecology and Agriculture in Zurich have shown the potential for genes, designed to provide resistance to pest insects, to have adverse effects on predatory beneficial insects (ladybirds and lacewings) via the food chain. Both these studies were conducted under laboratory conditions and each tested a specific anti-insect gene (GNA lectin

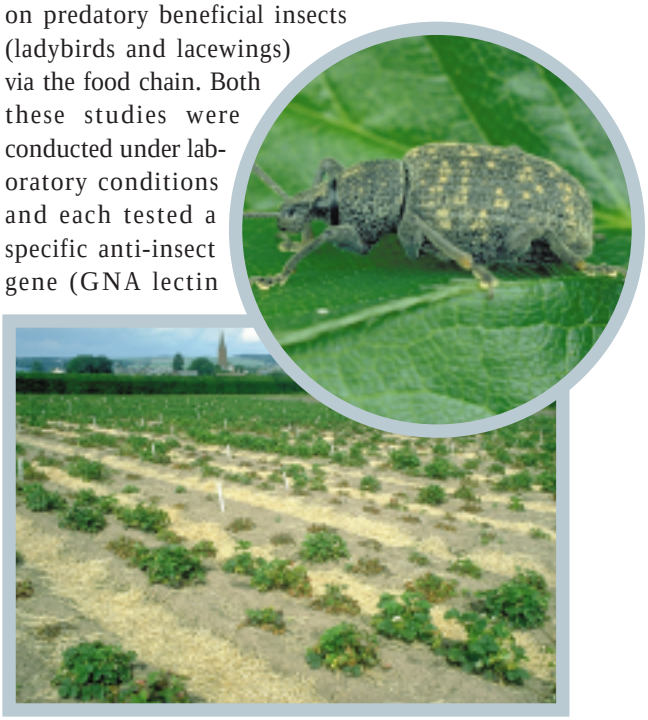

Figure 3 Strawberries damaged by vine weevils (adult weevil, inset) are a target for GM insect resistance.

and *Bt* toxin respectively). The wider ecological implications for these and other anti-insect genes remain to be investigated under more natural field conditions, where the interactions between species are much more complex and, in particular, predators have a choice of prey. The likelihood is that after each of these careful 'case-by-case' risk assessment studies, strategies can be developed which will minimise any adverse effects on beneficial insects to a level below that caused by many widely used pesticides. However, each new promoter/gene/plant/pest combination will need to be carefully assessed under a range of environmental and agricultural conditions, so that we can ensure the new technology is effective and compatible with future environmentally-benign Integrated Pest Management systems. This will include checking for more subtle (sublethal), longer-term effects on the target pests, on other secondary pests of the crop, on beneficial insects, the GM crop and on wild / volunteer plants in the agro-ecosystem.

Another example where risk assessment is hampered by lack of data is with plants modified by insertion of a gene or non-functional sequence derived from a plant virus in order to make them resistant to that virus. Here, one perceived risk is that the inserted gene may recombine with the genome of another virus that happens to infect the plant, so as to create a novel pathogen. It is already clear that such events are extremely rare but not impossible, and also that most novel viruses that might be created in this way are feeble pathogens compared with those that have been refined by eons of natural evolution. However, research is continuing in order to elucidate the circumstances in which such risks might be important. Indeed, a substantial proportion of contained experiments with GM plants are concerned with the collection of risk assessment data of one kind or another (Fig. 4). It is important that scientists remain open-minded enough to accept that the data they are collecting may show that their 'pet idea' has drawbacks which mean it has to be abandoned.

Often, the biggest and most uncertain step is to assess the risks at the scale of the agricultural ecosystem. A process of 'scaling-up' is needed in which the results of specific experiments on GMOs in contained environments or small field plots are placed in a realistic context. Some types of research aimed at tackling ecosystem risk directly need not even require the use of GMOs themselves. This summer (1998), for instance, SCRI has deployed populations of oilseed rape 'bait' plants in the Tayside area in order to assess the likelihood of GM crops cross-pollinating feral and wild brassicas. The bait plants are non-GM cultivars, since there is no reason to suppose that GM plants will behave any differently in this respect. By combining plant-scale and ecosystem-scale knowledge, advanced mathematical modelling is then used to assess the potential for the spread and impact of GMOs on a regional scale.

Scaling from small plots to systems will nevertheless remain an area of scientific uncertainty and public interest, especially when the genetically modified trait, for example insect resistance, might influence more than one layer in the ecological food chain. This is another area where the predictive power of mathematical models can be very valuable.

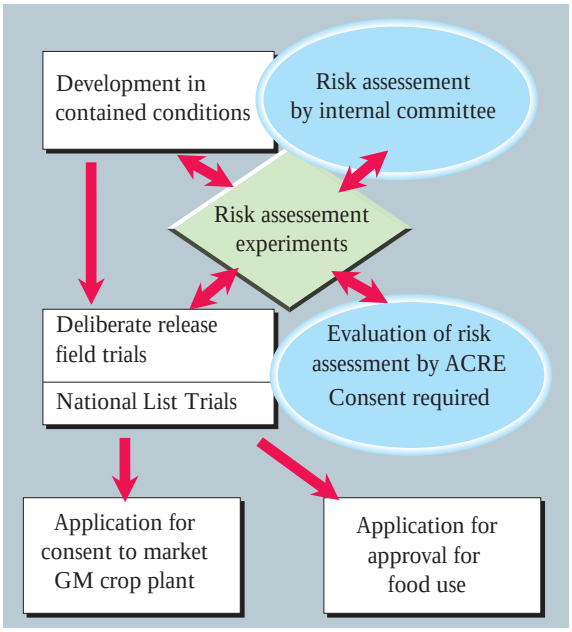

Figure 4 The pivotal role of experiments to provide risk assessment data in the development of a GM crop.

Release of GM plants. The next logical step in the development of a GM crop plant, after studies in containment, is field trials, properly called 'deliberate release into the environment for research and development purposes'. The R&D purposes may include the validation of results from contained experiments under more realistic conditions; it is well known that the behaviour of plants in the glasshouse is not always a reliable indicator of their behaviour in the field. In particular, levels of expression of introduced genes can be very different under different environmental conditions. Moreover, some characters cannot be sensibly tested in contained conditions, including yield param-

eters and characters such as potato tuber quality. These characters need to be assessed whether they are the object of the modification or not. The advantages, indeed the necessity, of field trialling GM crops rather than simply relying on data obtained from glasshouse trials has become increasingly obvious in recent years. For example, glasshouse selection of potato germplasm for improved crisping potential can bear little resemblance to performance in the field. This applies as much to non-GM as to GM crops. There are also cases where no phenotypic effect has been seen with GM plants in the glasshouse, but distinct phenotypic effects have been very obvious in the 'real' growing environment. As with traditional selective breeding, plants showing unexpected or detrimental phenotypes occur, and are discarded from the programme. In the longer term, the successful application of biotechnology will require a more comprehensive understanding of how the expression of any introduced gene is regulated by prevailing environmental conditions. However, modified phenotype does not necessarily imply a risk associated with the gene that has been introduced. Risk assessement, for any gene or gene product, must be carried out on a case-by-case basis. What these examples do show is the absolute necessity for controlled, regulated field trials that address all relevant parameters.

Once the potential usefulness of a particular GM plant for a particular agricultural application has been confirmed, the remaining steps in its development into a marketable crop are very similar to those for a variety bred by conventional selection. The agronomic characteristics of the plant may need to be improved and its genetic stability ensured by a programme of crossing and back-crossing with conventional varieties, and sufficient stocks have to be accumulated through seed multiplication or vegetative propagation. The next step may be to enter the GM plant as a cultivar in National List Trials, following which it will, if suitable, appear on the National List and be ready for the commercial farm market.

Throughout these development stages, up to and including National List Trials, work is regulated through a system of consents. It is an offence deliberately to release any GMO into the environment unless a consent to do so has been granted by the Secretary of State (consents are granted by the Secretary of State for the Environment, for Scotland, or for Wales depending on where the release will take place). A consent may contain conditions concerning the conduct of the release. Application for the granting of a consent involves compiling a dossier of data on the plant, the way it has been modified, the characteristics of the modified plant, the site or sites at which it will be released, the way in which the release will be conducted and managed, plans to monitor the effects and outcome of the release, the subsequent treatment of the site and emergency plans to cope with any unexpected events. A risk assessment must also be prepared, similar in concept to the ones for contained use, but dealing in much greater detail with all the possible interactions that may occur when the plant is introduced into the environment. When the application is submitted to the Department of the Environment, Transport and the Regions (DETR), a Public Notice must be placed in a local newspaper to inform the general public of the proposed release. The risk assessment and a summary of the data dossier are placed on a Public Register that is open for inspection, and information is also made public on the Internet. A summary (the Summary Notification Information Format or SNIF) is circulated to all other EU governments. The application is scrutinized for conformity with the regulations and for completeness of the data, and the risk assessment is analysed in detail. In this, officials are assisted by an expert committee (the Advisory Committee on Releases to the Environment; ACRE), which advises the Secretary of State whether and under what conditions a consent should be granted. The conditions always include a requirement to report on the outcome of the release and any effects it may have had on the environment. In addition, there is a general obligation on all consent holders to keep themselves informed and report to the Secretary of State any new information that might affect the risk assessment. Furthermore, releases are inspected (at the releaser's expense) by Specialist Inspectors from the Health and Safety Executive to ensure that practice conforms with the proposal. As with contained uses, where there are uncertainties about environmental effects, the worst-case is assumed, and R&D releases may often include the collection of data to resolve the uncertainties.

When it comes to marketing, a similar application format is required, but the degree of uncertainty permissible in the risk assessment is minimal, and there are some additional requirements about packaging and labelling of the product. In this case, the government that receives the application makes a recommendation to the European Commission as to whether consent should be granted, and the application is then circulated to all the other EU member governments.

Because a marketing consent is valid throughout the EU, the final decision is taken at Community level.

Eight Scientific Committees, involving independent scientific experts have been set up by the European Commission, grouped under common management within DG XXIV - 'Consumer policy and consumer health'. The Committees advise the Commission on questions such as food safety, animal nutrition, animal health and welfare, veterinary public health, plants, cosmetics and other non-food products, toxicity and eco-toxicity and the environment, medicinal products and medical devices. To ensure consistency and relevant information flow, members of any specific Scientific Committee also attend, on a case-by-case basis, workgroups organised by other Committees. For example, members of the Scientific Committee on Animal Nutrition and the Scientific Committee on Food provide inputs into assessments made by the Scientific Committee on Plants. Highly relevant to the acceptance of GM crops within the EU is the role of the Scientific Committee on Plants. Under Community Directive 90/220, this Committee is required once again to assess the risks to human and animal health and to the environment which may be caused by a commercial release of a GM crop into the environment. The Committee, composed of independent experts from several member states, advises the Commission using information based on current scientific knowledge rather than on ongoing politics within any specific member state. The Committee is not legislative; if a vote is required on a proposed decision, it is taken on a qualified majority basis in the 'Article 21 Committee', which comprises officials representing each of the member governments. Basically, the Scientific Committee on Plants assesses the dossiers from companies wishing to release crops into the environment for commercial purposes. For example, the Committee must determine what DNA [gene(s)] from the vector has been incorporated into the crop and the potential risks associated with the gene(s) in the unlikely event that they are transferred from the GM plant to microbes in the soil or to animals fed on such crops. The impact on humans is also assessed in the case of accidental direct exposure to the plants, including the issue of allergenicity of the gene product(s), and potential hazards associated with the metabolites generated by the gene in question. On the environmental side, the Committee addresses issues such as wild species likely to cross-pollinate with the GM crop, the impact on such species should the gene be transferred (e.g. for herbicide resistance) and the potential impact on insect populations in the case of GM releases involving products toxic to specific insect pests. However, these assessments under Directive 90/220 do not cover directly the use of GM crops or derived products in the production of foods for human consumption; the regulation of these aspects is described below.

Other statutory hurdles The regulatory system described above considers only the safety issues involved in growing a GM crop plant, but of course most crop plants are destined for use as food. The safety of food products derived from GM crops is dealt with quite separately from the safety of the plants themselves, because quite different kinds of expertise are required. Another expert committee (the Advisory Committee on Novel Foods and Processes) advises MAFF. Those who wish to market food derived from GMOs have to provide another dossier of data covering such aspects as toxicity, allergenicity, nutritional value, wholesomeness and effects on the overall diet. There is also a European dimension. The Regulation of the European Parliament and Council on Novel Foods and Food Ingredients was published in February 1997 and came into force 90 days after publication. The Regulation applies to the placing on the market within the Community of foods and food ingredients which have not previously been used for human consumption to any significant extent within the Community. The Scientific Committee for Foods plays a key role in assessing safety issues related to this area, but again the Committee is advisory and not legislative. Clearly there are relevant links between assessments carried out under Directive 90/220 and under the Novel Foods Regulation. However, even if products have been accepted under 90/220, they may not be placed on the market as a food or food ingredient until authorised under the Novel Foods Regulation. This further emphasises the scrutiny that GM crops and foods undergo prior to acceptance at Community level.

The factors that have to be considered are rather different depending on the form in which the crop is likely to be consumed. For example, a GM strawberry will probably be eaten as raw fruit, which is a live GMO containing viable seeds. However, at least for the present, GM crops will be eaten most commonly in a processed form, for example as soya meal or rape oil incorporated into prepared foods. In these forms, the GMO is dead, and processing may have eliminated the distinguishing characteristic(s) imparted by the genetic modification. The inserted DNA itself will

probably have been destroyed. Indeed, it may be impossible to determine whether soya meal or rape oil has been derived from a GM or a conventional crop (or a mixture of the two).

An important concept that is used here is that of substantial equivalence, i.e. that with the exception of the specific trait modified, the GM plants and products are equivalent in composition to their non-GM counterparts. This means that if the analytical composition and toxicological properties of, for example, oil from herbicide-tolerant rape are within the range found for batches of oil from conventional rape, there is no reason why it should not be used in the same range of applications. Incidentally, the potential difficulty in determining whether a processed product is derived from a GM or a conventional crop is one reason why governments are reluctant to impose labelling requirements that may be meaningless and unenforceable. However, arguments about the labelling of GMO-derived food are less to do with safety than with consumer choice, which is discussed below.

The use of a GM crop as animal feed may involve different considerations from its use as human food; for example, maize may be eaten unprocessed by cattle, but is cooked or processed for human consumption. The system for approval of animal feeds is similar to, but separate from, the human food regime.

Other forms of approval may be required for particular applications, such as herbicide-tolerant crops. The idea behind such crops, for example, glyphosate-tolerant oilseed rape, is that a wide-spectrum herbicide becomes entirely effective in that crop; glyphosate should kill all weeds but leave the rape unaffected. However, herbicides may only be used for approved purposes under approved conditions, and there is currently no approval for the use of glyphosate on oilseed rape, because conventional rape would be killed by it. To gain approval for the use of glyphosate on GM oil seed rape, a company must present the Pesticides Safety Directorate of MAFF with data on the efficacy of the herbicide and on its safety, including residues in soil and groundwater, effects on wildlife, the potential build-up of tolerance in weed species, etc. These data will of course have to be obtained in R&D release experiments that are themselves subject to consents. Concerns have been expressed about the effects of the widespread adoption of herbicide-tolerant crops on overall patterns of herbicide use and on crop rotations, and it is at this stage that such issues are properly addressed. Herbicide tolerance in a crop such as oilseed rape may well prove to be impractical in circumstances where the GM cultivar quickly becomes resident in the buried weed 'seedbank' of arable fields and waysides. Any factor, such as herbicide tolerance, which causes greater persistence of oilseed rape as a weed, will also increase the probability that a future crop of oilseed rape or turnip rape will be contaminated by the weeds left behind by a previous crop. The efficacy of the GMO as a weed will thereby act as its own regulator. If problems of this kind arise in practice and a worst-case scenario is realized, herbicide approvals can quickly be withdrawn.

Another issue that developers of GM crops have to face is how best to protect their property. In the US, there are two significantly different systems for the protection of plants: plant variety protection/plant breeders rights and the regular patent system. However, in Europe, even after the long-awaited EU Directive on the Legal Protection of Biotechnological Inventions, the position of patenting plants is still unclear. The Directive passed by the European Parliament on 12 May 1998 after some 10 years of debate, and a rejection by the European Parliament in 1996, clearly states under Article 4.1 that the following shall not be patentable:-

(a) plant and animal varieties, and

(b) essentially biological processes for the production of plants or animals

The term ‘essentially biological’ has not been judicially defined but is currently viewed as being applicable to traditional processes used to breed new plant varieties. Article 4.2 of the Directive states “Inventions which concern plants or animals shall be patentable if the technical feasibility of the invention is not confined to a particular plant or animal variety.”

In Europe, the protection of plant varieties and plant breeders rights are covered by national law established in the 1960’s and an international convention, the International Union for the Protection of New Varieties of Plant (UPOV, 1961). The protection is less robust than that of patents and includes exemptions for the use of protected varieties for further plant breeding and development, and for ‘farm-saved seed’, whereby a farmer can use seed saved from harvest for subsequent sowing on his own farm, subject to safeguarding the legitimate interests of the breeder. New varieties are granted protection if they meet Distinctness, Uniformity and Stability (DUS) criteria. The 1991 revision of UPOV has removed the prohibition on double protection by both patent and vari-

ety rights, and introduces rights to 'essentially derived varieties'.

It is currently held in professional patent circles that a plant patent should be protectable so long as it meets the criteria of patentability. In reality, because it is random and unpredictable, it would be hard to justify an 'inventive step' in traditional plant breeding of new varieties and, moreover, one could not define the genetic reason for or composition of most new traits emerging in a traditional breeding programme. Describing the invention is essential for the granting of a valid patent. Therefore, plant variety rights (PVR) are the preferred legal protection at the level of specific varieties.

Public perception Because the success of all GM crops used as food products will ultimately depend on acceptance by the consumer, public confidence in their safety and desirability is very important. Currently, such public confidence seems to be at a low ebb throughout Europe, in contrast with the position in North America where acceptance of GM crops by the majority of the populace does not seem to be a problem.

Figure 5 Tomato puree derived from GM tomatoes, a product that has been accepted by consumers.

Despite the strict EU/UK controls described above, and many years of experience of safety, the public does not seem to believe that GM crops are safe. Part of the difficulty arises from differences between the scientific and lay perceptions of risk. The scientist will always try to quantify the risk, and because of this the scientist is never able to say that there is zero risk. He has to fall back on an expression such as 'negligible' or 'effectively zero', by which he means that he can detect no risk, but appreciates that there is a limit to the sensitivity of his methods of detection. Notice, however, that this refers to absolute risk; at no point in the regulatory regime can a risk, however small, be traded off against a potential benefit, however great.

The lay person's perception of risk is rather different and does involve an implicit risk/benefit analysis. How else would anybody accept the risks of travelling by motor car, crossing a road, or bungee jumping? There has been no serious objection to the many vaccines that are now produced using GMOs, because the benefit is plain to see. In the case of GM crops, people are unwilling to accept even an infinitesimal risk unless they can see some benefit. It is notable that tomato paste made from GM tomatoes has sold well, despite being clearly labelled as derived from a GMO. Consumers can see the advantage because it is cheaper than paste made from conventional tomatoes and is of equal quality (Fig. 5). In contrast, products containing material from GM herbicide-tolerant soya beans have met with extreme consumer resistance. Here the consumer can see no personal benefit; the obvious benefits accrue to the grower, the seed producer and the herbicide manufacturer. The issue is not helped in this case by the fact that the beneficiaries are in North America and include multinational conglomerates. Furthermore, when EU governments insisted on scrutinizing the material under their own regulatory procedures before permitting its importation, threats were made to force the issue through the World Trade Organization, using trade sanctions. This only served to harden the antipathy of European public and political opinion, and it is to be hoped that the biotechnology companies involved now recognize that they scored a significant own-goal. It is unfortunate that the first major GM-derived foodstuff to come to the market in Europe was a commodity crop, where segregation to provide consumer choice is impracticable and uneconomic; even for non-GM crops, up to seven different varieties of soya beans are mixed at co-operative farm silos and shipped in bulk to processing facilities.

Effects on science and technology Despite the fact that in 1998 GM crops are occupying more than 60 million acres throughout the rest of the farming world, the political climate dictates that this is clearly not the time to relax the controls that are applied in Europe to releases of GM plants. There is however

some scope for simplification, and this is being addressed in the EU at the moment. For example, repeat experiments can be dealt with relatively simply; if there have been no significant changes, the risk assessment next year is likely to be the same as it was last year. There are also many facts that can be accepted without having to present detailed arguments each time. Strawberries are never going to become a weed problem in Scotland, and it is now well established that potatoes do not form viable hybrids with any native British species. Simplifications such as these save time and paper for the applicants as well as allowing the regulators to concentrate on any really contentious issues, without impairing the rigour of the regulatory regime.

Meanwhile, however, the complexity of the regulations causes problems for research organizations such as SCRI. The preparation of an application for even a simple GMO field trial is a substantial undertaking, and the monitoring of the trial, which may have to continue for several seasons after the termination of the experiment itself, ties up resources in an unproductive way at a time when those resources are becoming increasingly limited. If this work is to be carried out at public research centres such as the SCRI, then it is crucial that the costs associated with applications for and monitoring of such trials are reduced accordingly. Indeed, there is a very strong argument that research for the public good should be carried out free of extraneous charges. Moreover, our overseas competitors can make more rapid progress where they are in a less rigid and restrictive regulatory climate.

There is a noticeable reluctance on the part of independent scientists, such as those at SCRI, to become involved with releases of GM plants, because the benefits are often not commensurate with the huge resource costs. This is likely to lead to an increasing concentration of research on GM crops in the hands of large commercial companies. Although companies have to take account of the welfare of their customers, and are aware that they operate in a litigious society, their ultimate motive is profit. There is therefore a need for the independent public sector to invest in a thorough understanding of GM crops and processes. Especially in the area of risk assessment research, it is vital that a vigorous independent capability is maintained, but the rewards from this kind of work are minimal. The big rewards, in terms of added value and wealth creation, come through ownership of intellectual property rights or of a commercially successful cultivar. However, such rewards flow only from very substantial investments, and there is a need for investment to secure public ownership of platform technologies. It should be noted that even the large multinationals have not yet seen a return on their research investment. In 1995 in the US, sales of agricultural biotechnology products amounted to $100 million, whereas R&D expenditure was $2000 million. Economic analysts predict that 1998 will be break-even year for some sectors.

What is the future of GM crops? The demand for high quality, inexpensive food and food products has intensified in recent years, with retailers and consumers also expecting environmentally-friendly agricultural practices to be applied in generating such food supplies. The reality is that consumers have little knowledge of the methods and technologies used to generate the food supplies they currently purchase. Relatively cheap supplies of quality produce cannot be produced in large quantities without the use of agrochemicals. The developed world has evolved a sophisticated system to ensure food supplies and cannot revert to the practices used 50 years ago. However, agriculture must continue to evolve and, as we all realise, must encompass the issues of sustainability, environmental protection and safety to humans and animals. Are our current practices satisfactory in all of these respects? Clearly not. Pesticides can kill not only pests, herbicides can kill not only weeds, agrochemical residues may be detectable in groundwater and food. The use of arsenic and Bordeaux mixture (which contains toxic heavy metals) is permitted in organic farming. However, many perceive our current farming practices as relatively benign by comparison with the use of transgenic crops. There are many arguments that can be developed to demonstrate that this should not be so. Valid discussions must take into account our current methods of food production and the fact that the use of biotechnology provides approaches to crop improvemnt which are as safe as, if not safer than, our established practices. We must also be fully aware that sustainabilty will not simply depend on the use of GM crops in the future. Integrated Crop Management systems will still need to be applied in agriculture and horticulture. There will still be a place for agrochemicals and new germplasm generated in the traditional way by plant breeders. We cannot, as a nation, afford to close the doors on biotechnology. History has shown that such major advances in scientific discovery are rarely if ever held back. This is how we have reached

our present level of civilization and more than doubled average life expectancy in the past 100 years. Like it or not, science and technology have delivered a safer, more secure life for millions. However, we must follow best practice to ensure safety. The current legislation is there to protect. If there were to be a moratorium on GM crops in the UK, how could we possibly progress our understanding of the issues that arise? If we cannot evaluate these issues in controlled field trials without the plants being destroyed by a self-appointed faction of eco-vandals, the sound scientific answers that the public require will never be obtained.

At the present moment, public opposition, fuelled by the media and activist groups, against GM crops and products derived from them, seems likely to damage the biotechnology industry in Britain and Europe. Some of this opposition may be sincere, although much of it is misinformed and misguided, and to try to dismiss it out of hand is unprofitable. It has to be admitted that not all developments in biotechnology are necessarily beneficial, and some possible applications may need to be curbed. Indeed, almost all of the case studies cited by anti-GM activist groups are actually exaggerated versions of small-scale experiments (many in containment) where the beneficial trait failed to live up to expectations or a risk was detected that was unacceptable. This is precisely why GM crop technology has been subjected to over 15 years of extensive, unprecedented, precautionary risk analysis and testing. Rather than responding to risks or problems after the event, as with cattle feed contamination or food hygiene failures, GM crops have been, and continue to be, subjected to intensive risk analysis before being released.

Just as importantly, there are many GM crop applications that can be economically advantageous, environmentally beneficial and/or socially desirable. Perhaps the most important in all three respects will be applications that decrease the use of agrochemicals. Indeed, it has been suggested that the better public acceptance of GM crops in North America compared to Europe has been in part due to greater awareness of the benefits to the consumer and to the environment of diminishing agrochemical inputs.

Independent research organizations, like SCRI, must show the public what our GMO research is really about. We are not in the business of ramming transgenic crops and products down consumers' throats. We are exploring what is scientifically possible, whether what is possible is desirable, and whether risks are real or imaginary. This is not glamorous or short-term research, nor is it exactly wealth-creating, but in the present political climate it is probably wealth-preserving.