Bioethics Briefing

Number 2: Crop plant genetic modification

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Introduction to plant breeding

The practice of **selective breeding** of crop plants is very old, probably dating back at least 12000 years according to some authorities (Tudge, 1998). That is not to say that those early farmers had any inkling of how selection worked. Nevertheless there is clear evidence that as soon as plants were used in agricultural systems, even very simple ones, they were subject to selection. The evidence for this in respect of wheat is very clear and has been well documented. However, placing plant breeding on a scientific basis did not start until the 19th century. Experiments carried out in Devon by Goss during the 1820s showed that in peas, flower and seed colours were inherited as distinct characters rather than mixing or merging. He even noted evidence for recessive characters (without using that term) when he observed that some characters could disappear for a generation following particular crosses. Goss's work was thus a direct precursor of that of Gregor Mendel, working at Brno in Czechoslovakia, about 40 years after Goss. Mendel's extensive and systematic experiments on peas in the monastery garden, coupled with a detailed numerical analysis of the results led to confirmation of recessive and dominant inheritance patterns and to the discovery of the existence of genes. However, these developments based on Mendel's work were not initiated until the early years of the 20th century because his paper went virtually unnoticed until its rediscovery by three different scientists in 1900.

The science of genetics was thus established and soon began to inform the practice of plant breeding so that by the 1930s steady progress had been made in improving a number of the major crop species. However, it was in the second half of the 20th century that plant breeding made some particularly spectacular gains. In the UK for example, wheat yields are now several-fold higher than they were in the 1950s. But this progress brings its own problems. For example, when the selective breeding has been aimed at resistance to pests or diseases, the breeder is only a step ahead of nature because the pests and disease-causing organisms develop resistance. Thus, the breeder always needs new genetic variation to introgress into elite lines of crop species. Ideally, this genetic variation would be found in different populations of the crop in question or, for some crop species, in populations of readily hybridisable wild relatives. And in fact these sources of genetic variation remain, for many species, the stock in trade of the plant breeder, especially since the rapid growth of molecular genetics and map-based cloning (see below). For some crops, however, the desired genetic traits are not readily available. Faced with this problem, the breeder must find other ways of generating genetic variety. Sometimes this relies on achieving hybridisations that would not occur naturally. Thus, in the 1960s, plant breeders at Cambridge succeeded in introgressing into the wheat genome a fragment of a rye chromosome and a gene from a wild grass, *Aegilops squarosa*, in order to obtain particular genetic traits. Further, this was done before the advent of what we now call genetic modification (GM) and its success is a tribute to the ingenuity of the breeders. Other breeders have fused protoplasts derived from somatic cells, a technique that has had some commercial application.

More often however, the breeder deliberately induces mutations in the crop plant by exposure to gamma-radiation or to mutagenic chemicals. Amongst the surviving plants it is hoped that the mutations generated will lead to the expression of the desired trait. Although this seems very hit-and-miss, mutagenesis breeding is a well established practice and has led to the generation of new elite lines of both cereal and broad-leaved crops in several different countries. Nevertheless, identification of accessible genetic variety for the introgression of new traits is a constant problem for breeders and thus they greeted the advent of basic GM techniques with great interest, even several years prior to the application of GM technology to plants.

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Science Background

The advent of genetic modification

Genetic modification dates back to the early 1970s but it depended for its invention firstly on a slowly growing knowledge of genes (based on painstaking biochemistry and genetics) and secondly, within that growing knowledge, on certain key discoveries made in the previous decade. These were:

- Bacteria repel invading viruses by cutting the virus DNA in specific places.
- All living cells possess mechanisms for rejoining broken DNA molecules.
- Bacteria possess, in addition to their main chromosome, small 'extra' bits of DNA some containing only a few genes but others containing scores of genes. These are called **plasmids** and in nature many of them are transferable between bacterial cells.
- The viruses that invade bacteria (known as bacteriophage), provided they evade the bacterial defences, are also agents of gene transfer.

These discoveries led to the development of the essential tools for genetic modification:

- Cutting and rejoining DNA molecules[1].
- Changing the suite of genes present in plasmids or bacteriophage, *e.g.* by adding a new gene.
- Transferring the 'recombinant' plasmid or bacteriophage to bacterial cells.

The process is thus dependent on natural gene transfer mechanisms, albeit modified to achieve much higher frequencies of gene transfer than occur in nature, but the range of genes that it is possible to transfer into bacterial cells in the laboratory is much wider than would occur in nature. This immediately raises ethical concerns about the application of these techniques. The possible intrinsic rightness or wrongness of GM itself is discussed later. At this point, however, the issues of **safety** and of possible **misuse** need to be aired. In both these areas, the scientific community showed enough awareness firstly to call a temporary embargo on further experimentation and secondly, during that embargo, to devise safety and ethical guidelines for the performance of GM experiments and the use of GM techniques. These guidelines have formed the basis for **regulatory frameworks** across the world and in many countries these frameworks are enforced by government agencies. In the UK, even the research use of GM within laboratories is subject to regulation by the Health and Safety Executive and that agency may inspect a laboratory at any time. Furthermore, these government agencies are not toothless: laboratories may be closed, or at least prohibited from continuing GM work, and in both the UK and the USA, scientists who have contravened regulations have been moved to other work or have even been dismissed from their posts. Thus, in respect of a technology about which there were initial uncertainties, society has taken steps to protect both human beings and the environment and to prevent the technology being used against other humans. In the latter context, the regulations are strongly reinforced by international protocols prohibiting biological warfare. Although there have been some exceptions, as mentioned above, scientists in general have embraced the culture of care and appropriate concern and have welcomed these regulatory frameworks.

Once the regulatory frameworks were in place, the technique was very rapidly taken up by the **pharmaceutical industry**. Detailed discussion of this lies outside the scope of this briefing but some brief examples will serve as part of the background to subsequent discussion. The first commercial product of GM technology was human insulin. The cloning in bacteria of the gene encoding human **insulin** was reported in 1977 and by 1982 insulin produced by genetically modified bacteria was licensed for use in human therapy. It is often forgotten in these discussions, but it is a very pertinent point, that it is the universality of the genetic code that makes this possible. The bacterium 'reads' the human gene as if it were one of its own and makes a product, *i.e.* a human hormone, that it has never made before. This success has been followed with the production of many therapeutic proteins and of several vaccines in genetically modified bacteria and other micro-organisms. The technique has also been applied in the **food industry**. For example, it is used to produce an enzyme called **chymosin** for use in cheese making, thereby avoiding the need to extract the enzyme from calves' stomachs. Cheese made this way is sold as 'vegetarian cheese' and in commercial terms is a very successful product.

The development of GM techniques for bacterial cells was welcomed enthusiastically by biologists working with higher organisms. This was for two reasons. Firstly, the ability of

[1] i.e. recombining DNA molecules in new ways, hence the biologists' original term for these techniques: **recombinant DNA technology**

bacterial cells to incorporate foreign DNA meant that these cells could be used for multiplying particular sequences within cells, a process known as **molecular cloning**[2]. This, coupled with the development of DNA sequencing methods, led to a rapid expansion of the molecular analysis of genes in a wide variety of organisms, including plants. Further, the combination of the new molecular techniques with classical genetics paved the way for **map-based gene cloning** and for the various genome projects with which we are now so familiar. This contribution of basic GM methods to our current knowledge of genes is often overlooked but is actually very important.

Secondly, there was great interest in the possibility of **genetically modifying higher organisms** themselves. For plants this was first achieved, albeit at a very low success rate, in 1983. The initial development of plant genetic modification also relied on natural mechanisms, and especially on the manner in which a particular bacterium, ***Agrobacterium tumefaciens*** transfers some of its genes to plants. *Agrobacterium* is a natural pathogen of plants that enters the plant through wounds. The bacterium then transfers a small piece of DNA from a plasmid, the tumour-inducing (Ti) plasmid, containing some of the plasmid's genes, to host plant cells at the wound site. The transferred genes become integrated into the plant's DNA and provide the genetic information that causes the plant to form a gall and the cells in the gall to produce nutrients for the bacterium. This is effectively a form of genetic parasitism. It was quickly discovered that the genes that caused gall formation and the genes that caused production of bacterial nutrients were not needed. Based on study of this system, the essential features that in nature allow the transfer of genes to plants are now well understood. All that is needed in this piece of plasmid DNA are the short building block sequences that allow the DNA to be inserted into the plant chromosome. Between these two short sequences it is possible to place any gene, along with its promoter and then to let the bacterium transfer that to the target plant. Indeed, in some more 'minimal' versions of the mechanism, the bacterium has been dispensed with altogether and the DNA is 'shot' into the plant cells. This **'biolistic'** approach is especially suitable for plant species that *A. tumefaciens* does not readily infect.

This technique is both **precise** and **imprecise**. It is precise because, unlike 'traditional' plant breeding techniques, one or a few specific genes, conferring desired characters, are transferred to a plant, the rest of whose genetic characteristics are not altered. Thus, single wanted genes can be moved with precision into candidate varieties. This clearly contrasts with what happens in conventional breeding. However, genetic modification is imprecise because of ***position effects;*** there is no control over the place within the plant chromosome that the incoming genes are inserted and this causes great variation from plant to plant in the first 'GM generation' in the extent to which the desired character is actually seen (due to variation in the level of expression of the incoming gene). This means that there must be some selection of the first generation of GM plants followed by observation of the stability of inheritance in subsequent generations. However, in practice this phase is shorter than the 'sorting' and evaluation phase in conventional breeding, leading to a faster adoption of the new varieties. Thus the advantages of GM are that it enables the addition of specific genes to well-characterised varieties (without bringing in 'unwanted genes'), that those genes can come from widely separated species and that new varieties may more quickly be adopted for use.

Such was the interest in the development of plant GM that only about two years elapsed between the first successful experiment in the laboratory and the setting up, in 1985, of strictly regulated field trials of GM crop species in several countries. Commercial scale **field trials,** mainly but not exclusively in the USA were underway by the early 1990s and the first products of crop technology went on the market in the mid-1990s. The major GM crop is **herbicide-tolerant soybean** which was rapidly adopted in US agriculture. Between 1996 and 2002, the area devoted to this crop in the United States increased from 1.7 million to 34 million hectares. This represents about 70% of the US soybean crop. On a worldwide basis, in 2002, some 53 million hectares were used for GM crops, mainly in the United States but also in Argentina, Australia, Canada and China. Of the 5 million farmers in the world currently growing GM crops, 75% are small-holders in China.

The herbicide-tolerance trait has also been transferred to other species, including oil-seed rape and maize. Other GM traits in commercial use include resistance to insect pests and resistance to viral diseases. Many other applications are being developed (see Hughes and Bryant, 2002).

[2] The subsequent development of the polymerase chain reaction added another very powerful method for amplification of genes *in vitro*.

Ethical objections to GM crops

Background

Although particular GM crops have been adopted in the USA and several other countries, the same is not yet true of the United Kingdom, nor of much of the European Union. This is somewhat ironic in view of the prominence of European scientists in the early development of crop GM, including some very early field trials in the UK. The reasons for the current situation are complex, but there are certainly some ethical considerations that have had varying degrees of weight within the discussion.

Intrinsic objections

There are some opponents of GM technology who believe that moving genes between organisms is intrinsically wrong. In the language of moral philosophy their objections are deontological (see Bioethics Briefing 1 for more background). This view was first expressed when genetic modification of bacteria was developed in the 1970s but little more was heard of it until the widespread use of GM crops became a real possibility. In the UK some of the most ardent and vocal of the anti-GM campaigners hold this view, which some regard as being almost religious in character, and for them it is important to resist as far as possible the use in the UK of these crops. Obviously, intrinsic objections are not countered by experimental evidence and the position of people holding this view should be respected.

Safety concerns

- **Containment.** One of the concerns that has been dealt with by the regulatory frameworks is that of escape of GM organisms; the regulations relating to micro-organisms include strict guidelines on containment. However, by their very nature, crop plants are not contained. There are already millions of hectares of land devoted to GM crops. Some have described this as letting the genie out of the bottle on the grounds that GM crops present threats that conventionally bred crops do not.

- **Marker genes.** In the early stages of genetic modification of any organism it is necessary to distinguish between the cells that have successfully received the foreign DNA and those that have not. To this end, as well as the gene of interest, a marker gene is added that facilitates selection. In the laboratory it is convenient to use antibiotic-resistance as the marker. Cells that take up the foreign DNA can grow in the presence of the antibiotic. The first commercial GM crop varieties contain antibiotic resistance marker genes and concerns have been expressed that there is a chance, albeit very remote, that such genes may find their way from the crop plant to bacteria that infect humans or farm animals.

- **Food safety.** It has been suggested that the presence of foreign genes may cause the synthesis of unknown by-products or of new allergens.

- **Gene flow and superweeds.** Will the GM crop be able to cross with wild relatives thus allowing introgression of genes that change the character of the wild species, perhaps transforming it into an aggressive weed? Alternatively, will the GM crop itself be able to establish itself as a ‘superweed’?

- **Biodiversity and sustainability.** It has been suggested that several of the traits introduced into crops by GM techniques threaten biodiversity. For example, herbicide-tolerant crops may be subject to more frequent herbicide applications, thus reducing weed populations and in turn having an effect on organisms ranging from insects to birds that depend directly or indirectly on the weed species for food. Another example raised is the possibility that genes conferring resistance to insect pests may, by virtue of their presence in pollen, have an adverse effect on pollinating insects, including bees. Use of GM crops therefore, it is said, is incompatible with farming sustainably. Even though others have suggested that use of certain GM crops may contribute to sustainability (see below) opponents of GM argue that GM crops are part of the intensive high-tech approach to agriculture and therefore cannot so contribute.

Socio-political concerns

- **Intrinsic objections and personal choice.** One of the reasons for the increased level of protest in the UK was export from the USA to Europe of the products (bean meal, oil, proteins) of GM soybeans without any labelling to indicate the GM nature of the crop. Consumers were thus denied choice.

- **Focus of power.** Crop GM technology is, with the exception of that being developed in China, almost entirely in the hands of major commercial organisations in rich countries in the developed world. This, coupled with the way that current rules on world trade are operated, means that crop GM technology may be just one more way in which the economically strong dominate and even exploit the economically weak (see Food Ethics Council, 2003).

- **Gene patenting.** Although genes are not inventions, patent jurisdictions have granted many patents on gene sequences. This has the potential to increase further the power of the rich over the poor.

Responses to the ethical objections

Background

In the Introduction to this Briefing, crop GM technology was placed firmly in the context of plant breeding. Those who say that we do not need GM nearly always do so on the grounds that we (meaning the developed nations of the world) already produce enough food. If on these grounds we do not need GM then we do not need crop breeding. It is therefore as a plant breeding technique that crop GM technology should be ethically evaluated.

Intrinsic objections

For those with intrinsic or deontological objections to moving genes between organisms, there is no ethical defence of GM crops (see below, where socio-political concerns are dealt with).

Safety concerns

- **Containment.** There is no evidence that the techniques of GM *per se*, when applied to crop plants, present any more need for containment than other plant breeding methods.

- **Selectable markers.** It is conceded that there is a very remote chance of antibiotic resistance genes being transferred to bacteria. Thus it is important that if antibiotic-resistance genes are used as markers then the antibiotic that is used to impose selection should not be one that has applications in human or veterinary medicine. Further it is possible (although not with great ease) to remove the marker genes. However, in what might be called second generation GM crops, other marker gene systems have been developed.

- **Food safety.** Much has been made by some anti-GM campaigners of the tragic case of the contaminated tryptophan produced by genetically modified bacteria and because it contributes to the climate of the debate it needs to be discussed here. Tryptophan is an essential amino acid which is adequately provided in most diets. However, some people, such as vegans, take it as a supplement (as do many people who do not need it). The contaminated batches of tryptophan, imported into the USA from Japan, were produced by bacteria that had been genetically modified to over-produce the amino acid. In making large excesses of tryptophan, the bacterial cells converted some of the tryptophan to a by-product, di-tryptophan. It was this that caused a crippling muscle disease and in some cases death. It is all too easy to blame this on genetic modification but further investigation revealed the actual cause of the problem. In order to cut costs, the production company had eliminated two steps from the purification procedure and further, there had been a failure to apply rigorous quality control. This case, in fact, highlights a different problem, that so-called health supplements are, in several countries, exempt from food and drug safety evaluations. Indeed, at the time of writing this there is debate in the EU (including the UK) as to whether 'traditional' supplements and remedies should be subjected to the same analysis as conventional drugs.

  Although contaminated tryptophan may seem a long way from a GM soybean it is the experience of the present author that it is often raised in debate by those campaigning against GM crops. Are there then food safety problems with GM crops? Regulatory authorities have found no evidence at all that the technique of GM *per se* raises any food safety issues. Nevertheless, particular genetic traits introduced by GM techniques may cause concern. Thus, genes encoding potentially allergenic proteins should not be transferred to plants in which their presence would not be expected. And, plants containing a foreign gene that modifies a metabolic pathway must be subject to rigorous analysis as if they were completely novel crops (because of the possibility of unusual by-products). Overall however, with the GM crops in current production, there have been no food safety problems, a fact even acknowledged by some of the opponents of the technology.

- **Gene flow and superweeds.** Crop species are selected for growth and yield in agricultural systems and in general they perform poorly in the natural environment. Although it is true that some species can grow as 'volunteers' in the wild, they do not become established as ongoing populations. But will a new genetic trait, however introduced, make a crop species a better competitor so that it threatens native species or becomes a nuisance?

The risk, if there is one, is related to the genetic trait in question and not to whether it has been achieved by GM.

But what about gene flow, the movement of genes from one crop variety to another or even from a crop to a related wild species? In the UK there are very few crop species that are known to readily outcross with wild relatives in Britain, but two of them, beet and oil-seed rape, are amongst the crops for which GM techniques have been developed. In very extensive studies of hybrids between oil-seed rape and wild mustard and wild radish, no evidence could be found for **establishment** of these hybrids (although they certainly occur, albeit at a very low frequency). Although we must not assume that it will not happen, it should be emphasised that GM crops are no more or no less likely to outcross than conventionally bred crops. The outcome of gene flow will depend on the genetic traits of the crop and not on the method by which the crop was bred.

However, there is one aspect of gene flow in which GM crops do differ from conventionally bred crops and that is in the flow to organically grown crops. In the UK, GM crops have been declared 'non-organic' by the organisation that validates organic crops, the Soil Association (expressing an intrinsic objection to moving genes between organisms). So for example, a farmer growing organic sweet corn[3] nearby to and down wind of a GM maize crop will certainly note some pollination of his or her crop by pollen from the GM maize. The concern then would be that the percentage of cobs 'contaminated' in this way exceeds the limit permitted for validation by the Soil Association. This is another example of where regulations need to take into account those who have intrinsic objections to GM.

- **Biodiversity and sustainability.** As a prelude to this section of the discussion it should be noted that intensive agriculture has contributed significantly to food security in developed countries. In the UK the ready and affordable availability of our 'daily bread' is attributable to the efforts of plant breeders and to intensive agriculture. However, intensive agriculture has had very marked effects on the landscape, the land and wildlife. Indeed, one very clear outcome of the farm-scale evaluations of GM crops (the results of which were published in 2003) is that we are much more aware of the effects of agriculture itself. A 'back-to-nature' approach is not workable; all farms, whether intensive or 'organic', are unnatural systems. Nevertheless, there is now a move to farm with an eye to sustainability – to minimise as far as possible effects on the environment. It has been suggested that GM technology may help to promote sustainability by producing strains that require less 'chemical support', *e.g.* that are resistant to predation by insects (and of course the same is true of other techniques in plant breeding).

  The farm-scale evaluations that have recently finished in the UK illustrate clearly that it is **genetic traits** that should be evaluated and not the **method** by which they were generated. Three herbicide-tolerant GM crops were evaluated. They were not compared to herbicide-tolerant strains generated by non-GM techniques (there are none such yet in commercial use but they are under development; see **case studies,** page 9). The comparison therefore was with non-herbicide tolerant but otherwise similar strains. It is immediately obvious that what is being tested here is the herbicide-tolerance trait and the associated system of crop husbandry. In all three, more efficient weed control was achieved but with two of them, both oil-seed rape varieties, there was some above-ground reduction in biodiversity in and immediately around the fields of crops (no attempt was made to study below-ground biodiversity) while with herbicide-tolerant maize there was a slight increase in biodiversity. Genetic scientists may well join with the anti-GM campaigners in suggesting that the trials have told us very little. However they do indicate that GM as a technique should not be a specific target of concern. It is what is done with it (or indeed with any other plant breeding technique) that should be evaluated.

Socio-political concerns

- **Intrinsic objections and personal choice.** This is a difficult topic. In principle, labelling of the products of GM crops is an appropriate action to take but pragmatists will suggest that in practice it is very

[3] Maize and sweet corn are the same species; sweet corn is a mutant that fails to turn much of its sugar into starch

difficult. How far along the chain should labelling go? For example, will restaurants need to state in their menus that certain items are from GM crops? At present, many make the claim that their food is GM-free whilst others, with a different purchasing policy, state that they cannot guarantee that their products are GM-free. In this area of conflict between personal morality (and hence personal choice) difficult situations always arise and it is hard to predict how this one will be resolved.

- **Focus of power.** The author of this briefing is certainly concerned about the focus of economic power, the inequalities of the distribution of wealth and the workings of the world trade systems. However, although some organisations have suggested that crop GM technology not only typifies these problems but may exacerbate them, this seems to be blaming a set of techniques for problems which are global in scale and socio-political in character (see discussion on **global food security,** page 8).

- **Patenting.** The author of this briefing holds the view that neither genes nor copies thereof should be patented. However, others have argued that there are no ethical objections to patenting genes, provided that the system does not discriminate against the poorer nations of the world (see Hughes, 2002).

Wider issues

Global food security

One of the more expansive claims made by some proponents of GM technology was that it would 'feed the world'. This claim needs to be looked at in relation to world food supply. The current world population is about 6.3 billion and on a world-scale, enough food is produced to feed them all (and more); yet, many are starving. It is not failure in global food production that is to blame for hunger but inequalities in wealth. People starve because they are too poor to afford to buy food and this happens even in countries that are net exporters of staple foods such as India (Bharathan *et al*, 2002). No plant breeding technique will overcome major global economic problems and yet plant breeding can contribute to greater food security by producing strains that will perform well in particular environments, enabling poor farmers to obtain better yields from their crops.

The ability of the world to produce excess food, irrespective of the fact that many do not benefit from this, is due in large measure to plant bleeding and changing agricultural techniques. However, Gordon Conway, the Director of the Rockefeller Institute, has noted that the rate of increase in the world's human population is greater than the rate of increase in food production. Some time in the first half of the 21st century the former will outstrip the latter and at that point there will be an actual shortage of food. He urges plant breeders to work for a 'doubly green revolution' and notes that GM technology should be one of the tools involved in the plant breeders' efforts. This makes it even more important that the technology should be freely available in less developed countries in order to incorporate it into their breeding programmes. So, the claim that GM techniques will feed the world is not supportable (see below) but they can contribute to plant breeding programmes aimed at improving food security in less developed countries (see Bharathan *et al*, 2002; Nuffield Council on Bioethics, 1999).

Conducting the debate

In the UK, the results from the farm-scale evaluations were published in late 2003. At that time, Professor Robert May, the Government's Chief Scientist and Professor Joe Perry, closely involved in analysing the results of the trials, both made very strong criticisms of the way that the debate had been conducted (indeed is still being conducted). Both sides, it was suggested, had made exaggerated claims, had introduced misleading red herrings into the debate and even propagated deliberate untruths. Just four examples from amongst many will suffice:

- The scientific community was justifiably excited by this range of techniques. Their uptake into research has given us information that we could not dream possible even 30 years ago. Their use by the pharmaceutical industry, alongside other techniques, has led to the production of a range of safe and effective products. And yet GM actually remains a set of techniques amongst a range of others. If GM methodology is placed in the context of plant breeding it is simply one more tool, albeit a powerful one, available to the breeder. It is thus simply untrue that GM will feed the world.
- In a particularly notorious example of misleading practice, one of the major biotechnology companies produced a series of advertisements in British newspapers. However, careful reading of the advertisements revealed that they were actually subtly worded propaganda for crop GM technology.
- There have been several occasions when anti-GM protestors have ripped up GM crops (and often the media 'happened' to be present). Not only is this a criminal act, but the wearing by the protestors of chemical protection clothing was a deliberate (and indeed successful) attempt to say to the public that these crops were so dangerous that this type of protection against contact was essential. This was therefore making a grossly untrue statement about these crops.
- A similar point may be made about the use of the terms 'Frankenstein foods' or 'Frankenfoods.' This conjures up the picture of a mad scientist making a monster that turns out to be uncontrollable, a far cry from the reality.

Perry has suggested that these examples and many others should make the protagonists on both sides ashamed of themselves whilst May states that the way the debate has been conducted has not served to inform the public about the real issues. Intensely held views should not eliminate ethics from the way the debate is conducted.

Case studies

Case study 1 *This study assumes that the UK government has given the go-ahead to grow certain GM crops.* You are a District Councillor in a region noted both for tourism and for agriculture. One of the district's advantages is a mild winter climate, enabling farmers to produce some of the earliest crops in the UK as well as some more exotic crops. In common with other districts in the county, there are several farmers' markets and about 15% of local produce is claimed to be 'organic'. The county's commercial development agency has been working on 'branding' the whole county (including your district) and its products in order to increase market penetration. 'Local foods from lovely Loamshire' is their favourite strapline; the Lovely Loamshire designation and its logo are registered trademarks.

The Council is about to debate a motion, proposed by a Green Party Councillor and seconded by an Independent Councillor, that the District should ban the growth of GM crops. Your task, as the senior member of your party's group on the Council is to set out the issues in a clear way, as unbiased as possible, so that your group can discuss the issue at its meeting to be held before the Council's debate.

Notes for instructors

Case study 1 This case study is based on real debates that are taking place in several areas. The author of this briefing has had direct experience of such a debate in the southwest of England.

The first key question to ask is whether the proposal to ban GM crops is specifically linked to the promotion of local produce or whether the proposal represents a more fundamental objection to GM crops (with the current marketing initiative providing an opportunity to propose a ban). If the objections are based on GM itself, we will need to understand what they are, whether they are convincing and widely tenable. Such objections may be deontological – the idea that GM per se is morally wrong and therefore there is a duty to ban it. On the other hand, the objections may be consequentialist – for example, GM crops may be thought of as dangerous to the environment or as posing unknown risks in terms of food safety. If these objections are widely tenable then we may believe that a ban is justified anyway, whether or not we agree with them. If so, we may be acting virtuously, taking notice of other peoples' scruples, or perhaps in a utilitarian manner, ensuring the greatest level of satisfaction.

Secondly, if there are no fundamental objections, are there still reasons why the local council may vote for a ban? The question mainly revolves around the matter of whether the concept of GM is compatible with the branding of local produce. The marketing department is doubtless using words such as natural and wholesome and will use the number of organic farms as another marketing point. In making these points, the marketing department is certainly responding to public perceptions where natural = good and un-natural = bad. How far are they justified in making these linkages? Further, GM is certainly cast in the public mind as un-natural, which may be a further reason to ban it. Finally, there is the question of organic agriculture. In the UK, the organisation that validates nearly all organic farms, the Soil Association, has outlawed GM crops. We may wish to question this, but nevertheless, in the UK and in the minds of the British public GM crops are clearly regarded as non-organic. Again we may wish to ask whether organic is necessarily better than non-organic, but this discussion will not affect public opinion.

Thirdly we will consider the possible commercial outcome of imposing a ban. The marketing department is likely to support a ban because, based on the arguments set out above, it ties in very well with their marketing initiative. Arguments for a ban are thus consequentialist/utilitarian: our region will do better economically if a ban is imposed.

Finally, there are legal arguments. Will a ban on GM crops restrict unfairly the trade of any farmer who wished to grow them? If the UK government and the EU approve the growth of particular GM crops, what is the legal status of a locally imposed ban on such crops? How far are the moral objections of individuals or the commercial concerns of local councils to be upheld?

Case study 2 At the request of a consortium of farmers and growers, three plant-breeding companies have undertaken a project to produce herbicide-tolerant mustard.

One company decided to use **conventional breeding** techniques. However, there were no herbicide-tolerant lines in its germplasm stock and extensive testing of wild mustard populations had also failed to come up with the desired trait. The company therefore opted for **mutagenesis breeding.** After several attempts, the herbicide-tolerance trait was detected and introgressed back into the elite strain by a series of crosses. This led to the production of a strain of mustard that showed the desired level of tolerance in field trials.

The second company took an essentially **biochemical approach**. The gene encoding the enzyme that the herbicide inhibits was subjected to in *vitro* site-directed mutagenesis and the mutagenised gene, under the control of a strong promoter, was inserted back into the mustard plants. This led eventually to a line of mustard plants still able to carry out the relevant metabolic pathway but in which the key enzyme was not inhibited by the herbicide. As with the first approach, successful field trials confirmed this.

Company three also decided to target the same enzyme. However, they took a more directly **GM approach**. After screening populations of micro-organisms from farm soil that had been exposed a number of times to this herbicide, they discovered a benign bacterial species in which the relevant enzyme was not inhibited by the herbicide. The company therefore transferred the relevant gene to mustard plants under the control of a strong promoter. The eventual outcome again was line of mustard plants still able to carry out the relevant metabolic pathway but in which the key enzyme was not inhibited by the herbicide. As with the other two approaches, successful field trials confirmed this.

You are a member of a joint committee set up by the National Institute for Agricultural Botany (responsible for registration of new crop varieties) and DEFRA, the Department for Environment, Food and Rural Affairs. *The committee's job is firstly to decide whether these mustard plants should be registered as (a) one new strain (b) two new strains (c) three new strains (d) not recognised at all as new strains*; secondly, to make recommendations about whether immediate or conditional permission should be given to grow these mustard crops; thirdly, if conditional permission is given, what conditions will need to be met before commercial planting is allowed. Give reasons for your answers.*

*Recognition of a new strain requires that it is genetically distinct from pre-existing strains.

Notes for instructors

Case study 2 This case study is also based on real situations. Current herbicide-tolerant crops have been genetically modified using genes encoding enzymes which, unlike the plant's own version of the enzymes, are tolerant of the herbicide. However, mutagenesis breeding (the attempt to generate the appropriate trait by exposing seeds to mutagenic agents) and site-directed mutagenesis of the relevant enzymes are both under active research. The general aim of this case study is to place GM within the pantheon of plant breeding techniques and thus to ascertain whether GM raises ethical issues that are not raised by the other techniques (the fact that the end-result of all three approaches is in practice the same, facilitates this evaluation of the techniques).

In this case study, it is likely that all three lines of mustard plants would be given the status of registered new varieties. However, the authorities are permitted to delay approval for commercial growth of crop varieties if there is the likelihood of environmental damage. Currently in the UK, the situation is complex because, in theory at least, the GM variety would need specific evaluation whereas the mutagenesis-bred variety probably would not (other than that carried out by the plant breeders during their evaluation of the crop). The position of the third variety, in which the plant's own gene has been subjected to site-directed mutagenesis and re-inserted, is more problematic. We should recall that, had there not been a widespread campaign against GM crops since 1999, approval was likely to have been granted for the commercial growth and sale of slow-ripening tomatoes in the UK (as opposed to purée made from such tomatoes which had been on sale since 1996). These tomatoes were genetically modified with one of the plant's own genes turned back to front. They also contained an antibiotic-resistance gene which acted as a selectable marker in the early stages of genetic manipulation.

Finally we should recall that some people hold a fundamental (deontological) moral objection to GM and that others believe that GM techniques are inherently more dangerous than other breeding techniques (the arguments here are usually environmental and consequentialist).

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www.bbc.co.uk
www.bbc.co.uk/radio4/science/seedsoftrouble.shtml
www.bbc.co.uk/science/horizon/1999/gmfood_script.shtml (script of ***Is GM safe?*** BBC2, March 9, 2000, which may be available to you locally as an off-air recording)
www.defra.gov.uk/environment/gm/fse/index.htm
www.foodethicscouncil.org
www.guardian.co.uk
www.nuffieldbioethics.org

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List of available Bioethics Briefings

The following Bioethics Briefings are freely available at http://bio.ltsn.ac.uk/resources/ethicsbrief.htm

Briefing 1: Ethics and Bioethics

Briefing 2: Genetically Modified Crops

Briefing 3: Pre-implantation Genetic Diagnosis

Briefing 4: Xenotransplantation

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