# Gene Flow from GM Plants

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# Preface

The development of GM crops has stimulated intense research interest in the possibility of gene flow between these plants and their wild or weedy relatives. Unfortunately, in spite of the investment of considerable effort and money in these activities, we are still too often unable to quantify the risks of ecological damage associated with gene flow. This is due partly to the huge breadth of knowledge required to assemble a comprehensive risk assessment. For instance, many scientists active in research on the mechanics of gene flow nevertheless lack a deep understanding of what is required to identify, characterise and assess ecological risk. Conversely, many of those who are aware of the risk assessment process and the framework used for legislation have insufficient knowledge of the reproductive biology, agricultural systems, modelling and ecological literature required to compile a balanced assessment of risk. There is a need therefore for a holistic source of reference that brings together the knowledge and information required for the risk assessment of gene flow from GM plants, and allows us to explore the possibility of managing risk. This book combines the expertise of all the various stakeholders, allowing readers to view the whole jigsaw. It will also serve as a manual for assessment, measurement and management of the various categories of risk associated with gene flow from GM plants.

The book is structured in three sections. Section 1 (Chapters 1 and 2) sets the scene, section 2 (Chapters 3–8) focuses on identification and quantification of risk, and section 3 (Chapters 9 and 10) focuses on risk management. It is important to see where science fits into the "GM debate", and the initial chapter describes the UK case study of the GM Nation debate and the GM science review. The diversity of GM crops/traits is often ignored in the black and white discussions about the merits and potential pitfalls of biotechnology. The power of recombinant DNA technology is evolving rapidly and the new developments (Chapter 2) may affect the cost/benefit analysis and regulatory process (see Chapters 9 and 10). Identification and quantification of the risks associated with gene flow require knowledge of the mechanisms of pollen dispersal (Chapter 3) and hybridisation events (Chapter 4). Details of how to measure rare hybrid events (Chapter 5) and the ecological fitness costs (Chapter 6) are equally essential if one is to be more quantitative in risk assessment. Since risk is a function of hazard and exposure, prioritization of the hazards associated with gene flow (Chapter 7) and quantification of exposure levels to the "hazard" (Chapter 8) are essential components of any risk assessment framework. Management of the risks associated with gene flow requires stringent regulation (Chapter 9), a process which is frequently misunderstood by non-regulators. However, if the number of GM crops requiring regulation increases, there is a need to adjust the ways in which both the risk assessment is conducted and the data generated are used to guide regulation (Chapter 10).

We currently stand at a threshold. Gene flow from GM crops poses risks at many levels, but the use of GM crops can also bring many benefits. The cost/benefit analysis requires significant information, which in many cases is not available. In this book, we have tried to provide comprehensive coverage of the scientific, regulatory and management issues relating to gene flow from GM crops. Undoubtedly there is a pressing need to increase crop productivity, especially in parts of the world where pests, diseases and other stresses are significant. The use of GM crops has the potential to be a vital tool in the toolbox available to address these problems, but issues such as gene flow mean that their use will never be risk-free. This book has been written to inform readers and to allow them to make their own judgments on how best to proceed.

We would like to take this opportunity to thank the authors for their work in producing chapters of such a high standard – and in some cases on time! We would also like to thank Graeme MacKintosh and David McDade of Blackwell Publishing for their support and "gentle pressure" throughout the development of this book.

Guy Poppy and Michael Wilkinson

# 1 Where science fits into the GM debate

Philip J. Dale

## 1.1 Background

The science of plant breeding has advanced significantly over the past 80 years, and during this time there have been many important innovations (GM Science Review, 2003). GM methods of plant breeding, developed over the past 20 years, allow us to isolate genes from different classes of organisms (unrelated plants, microbes, animals) and incorporate them into a wide range of crop plants. The land area covered by GM crop cultivation increased steadily from the first small-scale field experiments in 1986 to over 67 million hectares grown worldwide in 2003 (James, 2003). About 20 years ago, it was decided to introduce an additional tier of risk assessment for GM crops when compared with non-GM crops. Following this decision, there was a gradual evolution of regulatory oversight worldwide.

## 1.2 Regulation

The regulatory framework adopted for the assessment of GM crops varies in different countries, depending on whether they adopted new laws or adapted existing ones (Tzotzos, 1995). There are also differences in emphasis in deciding the triggers that bring regulation into play. In Europe, all plants and organisms modified by the direct uptake of DNA are regulated irrespective of the organism from which that DNA is obtained. In North America, greater emphasis is placed on the nature of the plant breeding product. However, the differences in practice are currently largely academic. All regulations recognise the importance of rational scientific analysis of each GM organism, case by case (GM Science Review, 2003, 2004). They recognise that from a scientific perspective, few, if any, generic judgements can be made about the safety and impact of GM crops compared with non-GM crops.

Even though there are differences in regulatory framework, the questions asked in risk assessment internationally are similar and include the following:

- What is the nature and function of the gene of interest in the donor organism?
- What is the effect of the introduced gene on the modified organism?
- Is there evidence of any change in toxicity or allergenicity in the modified crop?
- Is there evidence of a change in persistence or invasiveness in the modified crop plants?
- Are there impacts on (friendly) non-target organisms in the environment?
- What is the frequency and consequence of gene flow from the GM crop to sexually compatible weeds, feral plants and adjacent crops?

While adoption of the process of GM as the primary trigger for requiring a higher tier of safety assessment has merits, it also has weaknesses. The principal one is that very similar modifications (e.g. herbicide tolerance) achieved by GM and non-GM plant breeding, which raises comparable gene flow issues, are regulated very differently.

## 1.3 Stimulus for research

A significant consequence of the extensive risk assessment carried out on GM crops over the past 20 years has been the stimulation of research. The research community has been required to seek answers to questions about GM crops that have rarely been considered hitherto for any crop, irrespective of whatever breeding method was used to produce them.

Studies of gene flow and its consequences have formed an important part of the international research carried out to underpin the assessment of GM crops (see, for example, BBSRC, 2004; Kessler & Economides, 2001). Other relevant topics have included the following:

- The nature and characteristics of DNA insertion into plant genomes
- The stability and expression of introduced genes
- Gene promoter and terminator function and tissue specificity
- The impact of crops on agronomy and wildlife

As a result of about 15 years of GM-related research on gene flow, we now have a more comprehensive understanding of sexual compatibility between crops and related species, the degree of geographic association between crops and related species, the dynamics of pollen viability and dissemination, the success of hybridisation between plants at different distances and the opportunities for gene introgression over sexual generations between crops and other species in nature (see, for example, Lutman, 1999).

The high profile Farm Scale Evaluations (FSEs) involved assessment of the impact on wildlife of herbicide treatments associated with the cultivation of particular GM herbicide tolerant crops (Royal Society, 2003). A minor part of that programme studied gene flow by pollination, but the primary objective of the FSEs was to compare the environmental impact on wildlife of agronomic management practices associated with each GM crop and a comparable non-GM crop of the same species. These experiments raised important questions about the appropriate balance between the provision of weeds to feed wildlife and the production of agricultural crops. The FSE experiments were initiated to address specific questions about the impact of GM crops on wildlife, but ultimately raised fundamental questions about how we manage the competing aspirations for the use of farmland and the wider environment. I shall return to this topic in the discussion section.

This extensive biosafety research, stimulated by a desire to base a regulatory process on sound science, has been interpreted in different ways by those with an interest in the future commercialisation of GM crops. On the one hand, many within the regulatory processes view the extra research and regulation as a responsible expression of the precautionary approach applied to modern plant breeding. On the other hand, some in the public debate argued that if it is considered necessary to carry out a great deal of expensive additional research to assess the safety and impact of GM crops, they must be fundamentally different and innately more uncertain than non-GM crops. A classic catch-22.

## 1.4 Vigorous campaigning

It is fair to say that before and during the national public debate in the United Kingdom, there was vigorous campaigning on the commercial future of GM crops. It is also reasonable to state that the majority of campaigning over several years has been against the cultivation of GM crops by activist groups and by certain sections of the press. Some of this activism included vandalism of scientific field experiments designed to provide important data on the impact of GM crops compared to their non-GM counterparts (Elliott, 2003). The campaigning has been to an unprecedented degree for any recent scientific advance associated with agriculture. Throughout the history of plant breeding, there have been many developments, including mutagenised crops, polyploid crops, the use of wide hybridisation between normally sexually incompatible species and a number of other significant developments. Several of these developments carried very high levels of unpredictability that had to be addressed during testing and evaluation of the new crop varieties produced. But opposition to these methods was not adopted by campaigning organisations at the time, and the developments received little or no public or press attention.

The vigorous and polarised campaigning associated with GM crops frequently led to expressing the issues, including the science, in a manner intended to stimulate the greatest political, judicial and press impact (Dale, 2004). Regular use in the media of the terms ‘Frankenstein food’, ‘mutant crops’ and ‘genetic pollution’ is evidence of this, and has branded GM crops in the minds of many people as innately undesirable and even dangerous.

Negative campaigning has of course been common in the history of many areas of innovation and unfamiliarity, from smallpox vaccination to stem cell research, from steam engines to mobile phones. The early canal pioneers in the United Kingdom over two centuries ago were branded as ‘carving up the countryside with stinking sewers’. While precaution in research and development is essential, so is an appropriate opportunity for innovation and advancement.

This, therefore, was the backcloth to the public debate on the commercial future of GM crops held in the United Kingdom during 2003. It was the context within which science was expected to inform and underpin the debate.

## 1.5 The GM Nation Public Debate

The public debate was managed by a steering board with members holding a diverse range of opinions on GM crops. Members ranged from a company developing GM crops commercially to the manager of a campaign organisation committed to preventing the commercialisation of GM crops. This diversity of view within the steering board made its operations particularly challenging. The aims of the debate were:

- To identify and focus on grass-roots opinion within the general public
- To avoid polarisation as far as possible
- To develop a wholly open and transparent process
- To provide a process that is evidence based
- To provide an opportunity for members of the public to debate openly and to reach their own informed judgement
- To allow the questions raised by the general public to shape the course of the debate

In addition to overseeing the organisation of the public discussions, the steering board had to agree on the information to be given to the general public about the science and future potential use of GM crops. As one of the few scientists on the steering board, it was particularly difficult to accept that scientific information, accumulated over decades of research and verification, was categorised by some as a scientist's view borne out of vested interest. Evidence, for example, that the vast majority of the scientific community would consider self-evident (e.g. the central role of DNA in inheritance) was by some given the same value as an idea based on little or no evidence (e.g. a link between GM crops and severe acute respiratory syndrome, or SARS).

Issues relevant to the widespread cultivation of crops can be complex and difficult to communicate in public discussions by sound bites. Another difficulty is that people have become disconnected from agriculture and the origins of their food (Curry Report, 2002). As a result, standard non-GM practices in plant breeding and agriculture often came as a surprise in public discussions. This emphasised the importance of greater dialogue between scientists and members of the public, but made it difficult in the debate to place GM crops in an appropriate agricultural and plant breeding context.

The fact that the debates were carried out in the midst of intense anti-GM campaigning by activist groups and sections of the press also made it particularly difficult to have an informed, balanced and dispassionate discussion. While there were significant pockets of activity and involvement in the debate from the scientific community, many scientists appeared to find polarised argument and sound-bite communication uninviting and even futile. Well-informed and balanced dialogue was often the casualty.

## 1.6 Gene flow issues raised in the public debate

The frequency of pollination between crops and adjacent sexually compatible species at different distances is an important issue in the scientific assessment of the impact of GM crops, but precise frequencies of pollination were rarely discussed in the debates I attended. The concept of gene flow was rarely expressed in these terms, but rather as concerns about contamination and environmental damage. The salient issues raised are discussed as follows.

### *1.6.1 GM is unnatural*

A common view of those opposing commercialisation of GM crops was that GM plants are unnatural and alien and therefore any level of gene flow is unacceptable. There was the feeling among some participants that to move genes into crops from unrelated plants, microbes and potentially from animals was fundamentally unacceptable. Discussions about the remarkable similarity of genes from very different organisms and kingdoms, and questions of what defines a wheat gene, a bacterial gene or a viral gene, were again difficult to engage within the often highly charged atmosphere.

Comparison with crops bred by induced mutagenesis was raised by scientists contributing to the debate, to illustrate the successful and safe use of a plant breeding method that frequently has a higher level of unpredictability than GM. In practice this was a comparison difficult to communicate to those unfamiliar with the practicalities of genetics and plant breeding.

### *1.6.2 Genetic contamination*

The issue of cross-pollination with GM crops was most intense in relation to compatibility of GM crops with organic farming. The organic sector has decided that there is no place for GM crops in organic agriculture. While many agriculturalists believe there are compelling scientific and environmental arguments in favour of the use of pest- and disease-resistant crops to reduce or eliminate the use of chemical sprays in agriculture, including those used in organic agriculture (e.g. copper-based fungicide sprays), the organic sector has decided for the foreseeable future to prohibit GM crops from organic agriculture. There are different ways of interpreting this prohibition: on the one hand, as not allowing the deliberate cultivation of GM crops; and on the other hand, as zero tolerance of the presence of any GM plant material in the vicinity of an organic farm.

Interestingly, the certifying bodies for organic agriculture accept a pragmatic view when considering coexistence with certain kinds of farming. There is, for example, tolerance of a level of spray drift from neighbouring farmers. There is derogation in the feeding of organically produced animals when organically produced feed is in short supply (e.g. during the UK foot and mouth disease outbreak).

There is also a general tolerance of the movement of noxious weed seeds, pests and diseases between different farming systems. Some campaigners for organic agriculture, however, have argued for zero tolerance of the presence of any GM in organic crops. If successful, this would make it difficult for organic and GM agriculture to coexist. To my knowledge, however, no organic farmer in the United Kingdom to date has lost his or her organic price premium following production of an organic crop in the vicinity of a GM crop.

The fundamental difficulty is that one farming system, in this case the organic sector that occupies about 4% of the UK agricultural land area (including land in conversion, but excluding common grazing; AEBC, 2003), is attempting to define its product in a way that will prevent, or at least severely inhibit, the viability of any farmer wishing to grow a GM crop. The principal campaigners for organic agriculture argue that the consumers of organic food demand the absence of GM content. This is not independent of vigorous campaigning against GM crops and foods on their behalf, and the threat of removing the organic premium from farmers who produce crops containing GM material. Defining organic produce in this way is not without significant commercial interest on behalf of the organic sector.

### *1.6.3 GM and organic agriculture cannot coexist*

Although some opponents of GM crops argue for zero tolerance of the presence of any GM plant material in a non-GM crop, in practice there are no analytical methods capable of proving zero GM content. The limits of routine detection of the presence of GM material are generally considered to be around 0.1%, that is, one GM seed in 1000 non-GM seeds (AEBC, 2003). While this level of analytical resolution is feasible in a laboratory context, in agricultural practice, it will be difficult to stay below this threshold when GM crops are grown in widespread agriculture. This is because the adventitious presence of GM crop material can result from several sources in practical agriculture, including:

- The seed sample used to establish the crop (seeds are often multiplied abroad in countries where GM crops are commonly cultivated)
- The GM seeds remaining in seed drills, combined harvesters, transportation machinery and grain silos
- The GM seeds and plants found as volunteers in the field from previous cropping or are carried there by animals and machinery
- The GM seeds resulting from gene flow by pollination from a GM crop

While the 0.1% threshold is currently the self-imposed aspiration of certain sectors of the organic movement, the only level that has statutory authority in the European Union (EU) is the 0.9% threshold used for labelling purposes. Any crop that contains more than 0.9% GM content must be labelled as containing GM material. A crop with less than the 0.9% threshold need not.

### *1.6.4 GM crops will damage the environment*

Another issue raised in debates was the potential consequences of the transfer of genes introduced by GM breeding to natural habitats and wildlife. The concept of environmental impact from gene transfer was often referred to in generic terms as being inherently damaging to the environment. Concerns were frequently mentioned about the production of superweeds as a result of the transfer of herbicide tolerance genes from GM crops to weeds.

## 1.7 Findings of the debate

The main conclusions from the debate can be found elsewhere (GM Nation, 2003), as can be a detailed account of the lessons from the debate process (Understanding Risk Team, 2004; Defra, 2004). Some quotations from the report give important insights into the perspective given to scientific information in the debate process.

- 'It was not part of our intentions (the Steering Board) in this report to say whether the public were right or wrong about any GM issue, even on matters of fact' (Introduction to the Executive Summary).
- 'It (GM) is not only an issue in its own right but acts as a proxy for many other current concerns which provoke strong feelings' (Paragraph 45).
- 'There was a broad desire to know more and for further research'. 'They (some participants in the debate) want a corpus of agreed "facts", accepted by all organisations and interests' (Paragraph 5).

Often discussion began with GM crops but rapidly moved to broader issues around agriculture, the environment and governance. Although there was a general desire through research to know more about GM crops, the discussions, especially in large meetings, were rarely conducive to a detailed consideration of the current state of scientific knowledge. There was also little opportunity to discuss specific research needs for the future.

## 1.8 Discussion

In the heat of public debate, and its associated campaigning, it was easy to forget the context in which GM crops were being considered. Gene flow is a natural biological phenomenon that has been occurring between sexually compatible species since the beginning of agriculture. For some participants, they had already made up their minds and the science was almost irrelevant; they viewed the issue of the commercialisation of GM crops as principally ideological, ethical and/or political. In my view, to argue that GM crops are innately more hazardous than non-GM crops is like saying that a toxin gene from a bacterium introduced by GM is more hazardous than a deadly nightshade-type toxin introduced into cultivated potato by pollination. Both are equally unacceptable and regulatory measures must be in place to prevent the use of crop varieties of this kind.

There were participants who were genuinely searching for a balanced and informed perspective, but this was difficult in the large structured meetings where there was often a preponderance of contributors from campaigning organisations. Interestingly, one participant at a large meeting said to his fellow participant, ‘I came to this meeting to learn from well-informed people, rather than to discuss the issues with people who know little more than I do’. This has important lessons for future debates of this kind.

### *1.8.1 GM crops have become ‘a lightning rod’ for a range of concerns*

The GM Nation report clearly acknowledges that GM crops have become a proxy for a range of concerns. The issues raised in discussion included impact on wildlife, the industrialisation of agriculture, the extensive use of chemical inputs, the perceived increase in power of multinational companies the globalisation of trade, the use of fuel to transport food across the world, the commercial future of organic farming and trust in the government. The GM public debate in the United Kingdom followed a period of vocal public opposition to the UK government for its involvement in the invasion of Iraq. The commercialisation of GM crops, therefore, seems to have taken on a significance in the activists’ agenda and in the public’s mind far beyond that relevant to a scientific consideration of the risks involved from the commercialisation of GM crops in the United Kingdom – crops that worldwide already cover over twice the land area of the United Kingdom.

### *1.8.2 Difficulty of holding a rational discussion of GM crops in context*

In the broader public debate there was a marked lack of serious discussion about the broader agricultural context within which GM crops were being evaluated. The relevant broader issues include the following.

#### *1.8.2.1 Method not mission*

The debate concentrated on plant breeding method rather than on mission. A fundamental weakness of current reasoning on GM crops (and supported by the current EU regulatory process) is that similar plant breeding products with comparable gene flow and environmental impacts are viewed and regulated differently. For example, if a plant breeder produces a ryegrass variety that is tolerant to the herbicide glyphosate by both GM breeding and non-GM breeding, their regulation would be fundamentally different. The GM variety would require compliance with stringent assessment and regulation, probably costing hundreds of thousands of pounds. The non-GM variety, with similar potential environmental impacts, including those associated with gene flow, would require negligible comparable assessment or regulatory oversight.

An excessive preoccupation with the GM method also ignores the fact that there are significant advances being made in the efficiency of non-GM breeding that have the potential to produce novel crops. There is, for example, important progress in the targeted selection of induced mutations (Targeting Induced Local Lesions in Genomes – TILLING; Chapter 4 of GM Science Review, 2003), which, for some applications, may prove as powerful as GM plant breeding. This again highlights the question of whether assessment of the impact of gene flow should be determined by the breeding process or the nature of the breeding product. In my view, from a scientific perspective, a proportionate analysis of the characteristics of the breeding product should be paramount, irrespective of the breeding method used.

#### *1.8.2.2 The FSEs raised wider issues*

The Farm Scale Evaluations (FSEs) were a significant topic of discussion in the GM debate and the science review. While these were admirable, pioneering experiments and of great credit to the scientists involved, they present some significant challenges.

The experiments, as indicated earlier, evaluated the impact on wildlife of the herbicide treatment associated with cultivation of three GM crops, each modified to be tolerant to one herbicide. The GM crops were grown adjacent to a non-GM variety of the same crop, essentially using the variety and agronomic management the farmer would normally use, for comparison. The use of a comparable non-GM crop as a control is perfectly justifiable as a measure of statistical significance of the kind important for publication. The real difficulty is in establishing whether statistically significant differences are biologically significant in wider agricultural practice, where there is considerable variation in choice of crop and agronomic management. The main potential pitfall is that this type of 'narrow sense' control may be adopted by the EU regulatory process as a gold standard for assessing not only statistical significance but, more importantly, biological significance.

My concern is that a control of this kind provides no holistic yardstick that facilitates judgements about whether particular GM crops have an acceptable biological impact or not. If we are to use the narrow sense control, as in the FSEs, to judge the acceptability or otherwise of particular GM crops, then it would be logical to question all conventional crops and agronomic practices that have a greater adverse impact on the environment compared with these same FSE control crops. If we do not do this, then we are judging GM crops asymmetrically and unfairly against a highly subjective measure of biological impact.

As an illustration, the current regulatory position in the United Kingdom would support the continuous cultivation of winter wheat (non-GM) and judge it to be environmentally acceptable, but would prohibit the inclusion in the rotation of a GM oilseed rape break crop and would condemn it as environmentally unacceptable. In reality, the cultivation of continuous winter wheat is widely acknowledged as a major contributor to the reduction of birdlife over the past 30 years, whereas the inclusion of a break crop of GM oilseed rape would be relatively beneficial to wildlife. It is the whole farming system that has profound impacts on wildlife and the environment, much more than single crops or treatments within it. If as scientists we do not question the use of these narrow sense measures of biological impact, then by default we legitimise them. Just as we are now critical of the decisions of former generations who removed trees, hedges and ditches and drove agricultural production at cost to the wider environment, so future generations will judge us for our narrow and blinkered perspective in assessing the current environmental impacts of particular GM crops. The challenge is to find measures of biological impact that operate at the level of the farming system, and make judgement accordingly.

### *1.8.3 Broader agricultural issues*

It was also surprising that there was little mention within the GM debate of wider issues in agriculture. In the heat of the discussions on GM in the United Kingdom, the EU independently decided to reduce the area of set-aside land from 15% to 10%. This single change, arguably, has the potential to make a much more profound impact on the agricultural environment than commercialisation of the GM crops being debated. Another potentially significant event in the EU is the reform of the Common Agricultural Policy. This may provide an important opportunity to give incentives to farming systems that benefit wildlife and the wider environment, and practices that would benefit from future advances in the breeding of pest- and disease-resistant varieties.

### *1.8.4 Political context*

There are many issues in which science and politics are uneasy bedfellows. It is clear that the debate about the commercial future of GM crops has become one of them. Engaging the public in a well-informed scientific dialogue, especially against a background of intense campaigning, is exceedingly difficult. It is important that society has access to the best science available, and as scientists we must be ready to discuss gaps in knowledge and areas of ignorance. We must also be more ready to discuss how precaution is used to manage risk. There is little science can do to resolve ideological differences except by providing underpinning knowledge to guide reasoning and discussion.

It is important that decision making about scientific innovation has a political element. Ultimately, politicians have to respond to their electorate. What is dangerous is when politics begins to influence the interpretation of science. Lysenko set back the science of genetics in Russia by several decades because idealism was used to interfere with the interpretation of science. Striking an intelligent balance between scientific logic and long-term political ideals is likely to present a challenge for a while longer until GM crop products have a clear and definable benefit to people, many of whom have little knowledge or empathy for the practical needs of agriculture.