GM CROPS, RISK ASSESSMENT, BEES AND HONEY

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GM crops and bees

The most significant scientific plant-breeding advance of the last 20 years has been the ability to isolate genes from any organism and, by recombinant biotechnology, to introduce them into crop plants to produce genetically-modified (GM) crops. This technology differs from conventional plant breeding in allowing a greater range of genes to be inserted and with greater precision, thereby producing 'a plant in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination'.

Farmers worldwide are currently growing 44 million hectares of GM crops. The major crops are maize, oilseed rape, potato, tomato, soybean, cotton, tobacco and sugar beet. Most GM crops are grown in USA, Argentina, Canada, and China with some in South Africa, Australia, Mexico, Spain, France, Germany, Portugal, Rumania, Bulgaria and Uruguay (Genewatch, 2001). To date, most GM crops have been modified for tolerance to specific herbicides or resistance to certain insect pests. Future advances in biotechnology will allow the development of a wider range of GM crops with enhanced resistance to disease, pests and herbicides, improved nutritive quality or greater tolerance of adverse growing conditions.

Understanding the interactions between GM crops and bees is important to risk assessment and the safe development and commercialisation of GM crops. Bees visit many GM crops for the pollen and nectar they produce and thereby contribute to their seed and fruit production through their pollinating activities. At the same time, they are exposed to any toxins that may be present in the nectar and pollen as well as to the management practices adopted to grow them; these may be beneficial, eg. reduction in pesticide use, or detrimental, eg. reduction in weed flora and hence bee forage. Bee visitation of GM crops has potential consequences for gene flow into the environment and for the health of humans when they eat honey or pollen harvested from GM crops. Increasing consumer demand for food safety, choice, and traceability is creating new challenges for the beekeeper marketing honey and other bee products from GM crops.

Risk Assessment

European Framework

The European Regulatory Framework for GM crops is far more rigorous than for the introduction of other technological and agronomic changes in farming, which mostly concern new seed varieties (Ministry of Agriculture, Fisheries and Food, 1998). Releases and marketing of GM crops can only take place with the explicit consent of the regulatory authorities in Member States as controlled by Council Directive 90/220/EEC (to be replaced by Directive 2001/18/EC in October 2002). Both Directives set out two regulatory regimes, Part B for controlling releases for research and development, and Part C for placing GM organisms (GMOs) on the market. They require any person, before releasing or marketing a GMO, to submit a notification to the competent authority of the Member State within whose territory the release is to take place, or where the GMO is to be marketed for the first time. Part B decisions are made by individual Member States. Part C decisions are made by all Member States and, once issued, apply across the whole EU. Directive 2001/18/EC provides a stronger regime for controlling releases of GMOs, imposing a 10-year limit on consents for most GMO products, more specific labelling and improved traceability of GMOs and post-market monitoring plans.

Similarly, no-one can market GM Foods in Europe without prior approval. The EU Novel Foods Regulation 258/97 provides for a statutory, pre-market safety assessment of all novel foods, including those from GM sources. An application for approval is first considered by one Member State, for an initial opinion, and then by all other Member States. If there are no objections, the GM food can be marketed throughout the EU. To date, 18 products have been approved for commercial release including GM soya beans, oilseed rape, chicory, carnations and four types of maize. GM maize, soya and oilseed rape are already imported into Europe for processing and animal feed.

UK Legislation

In the UK, Directive 90/220/EEC is implemented by the Environmental Protection Act 1990 and the Genetically Modified Organisms (Deliberate Release) Regulations 1992 (Department of the Environment, 1993, amended 1995 & 1997). No GM plant may be released without prior consent from the Secretary of

State. All Part B applications for research releases are submitted to DEFRA, the Department for the Environment, Food and Rural Affairs. The Advisory Committee on Releases to the Environment (ACRE) advises The Secretary of State, via DEFRA, on the safety of GMO and non-native releases into the environment. ACRE is a scientific and technical committee made of leading experts in subjects such as ecology, entomology, plant breeding, pollination, microbiology, plant and animal molecular biology and toxicology. In issuing consent, the Secretary of State also takes account of views expressed by other Government Departments, the Statutory Nature Conservation bodies and the general public.

An applications for release of a GM plant consists of a dossier of information composed of the responses to 41 questions (Department of the Environment, 1994; Department for the Environment, Transport and the Regions, 1999). These responses build up a detailed description of the GM plant, how it has been modified and the conditions of the proposed release. A detailed risk assessment considers the potential harm that may be caused to human health and the environment and identifies ways in which the risks may be avoided or minimised. All applications are dealt with on a case by case basis and consider gene flow as well as effects on non-target species, such as bees. In the UK, a total of 199 applications for release have been made (to end 2000), mostly for herbicide tolerant oilseed rape, sugar beet and potatoes.

Other committees also advise the UK Government on GMOs. The Advisory Committee on Genetic Modification (ACGM) advises on the contained use of GMOs. The Advisory Committee on Pesticides (ACP) advises on pest control issues related to GMOs. The Advisory Committee on Novel Foods and Processes (ACNFP) advises on use of GMOs in foods. The Advisory Committee on Animal Feedingstuffs (ACAF) advises on the safety and use of animal feeds containing GMOs. The Agriculture and Environment Biotechnology Commission (AEBC) provides independent strategic advice on current and future developments in biotechnology which have implications for agriculture and the environment, on their ethical and social implications and their public acceptability.

Gene flow

Gene flow, (i.e. the movement of genes, in either pollen or seed, between individuals, populations or taxa), its potential and consequences, is an important part of the risk assessment of GMOs. Consideration is given to whether the inserted genes are likely to make the modified plant more persistent, more invasive or undesirable to other organisms or whether they are likely to be transferred to other organisms. A key concern is the possible spread of genes from GM crops into non-GM crops or into wild relatives, via pollen dispersed by wind or by insects, such as bees (Department of the Environment, 1994,1995). Bee-mediated pollen and gene flow is a function of the deposition of viable, compatible pollen from donor to recipient plants along bee foraging routes, and of the spatial dynamics of these foraging routes within bee forage areas (Williams, 2001a&b, Osborne *et al.* 2001). The adequacy of proposed gene flow risk management procedures, such as separation distances from potential recipient crops is assessed as is the need for a period of post-release monitoring eg for GM volunteers.

Pollen cannot be contained in field situations and consequently gene flow from GM crops via pollen transported by bees cannot be totally eliminated. Bee visits to crops for pollen and nectar can only be prevented on small plots, eg by netting them, but this is impracticable on a field or landscape scale. However, pollen and gene flow mediated by bees can be minimised by use of a trap crop to absorb pollen carryover from the GM release (Williams, 2001), by separating pollen donor and recipient plants spatially or temporally, or by designing crop plants that produce little or no pollen or pollen that is incompatible. Ways in which future GM crop design could be approached to avoid or minimise the inclusion of superflous genes or gene sequences, the superflous expression of introduced genes and the dispersal of introduced genes in the environment have recently been reviewed (Department of the Environment, Transport and the Regions, 2001) and some of these approaches have important implications for bees.

Eliminating or reducing pollen production by GM crop plants could be achieved by controlling flower or pollen production or by controlling pollen compatibility. The molecular basis of the processes that control flowering have now been determined in some plant species opening up the possibility of blocking flowering in GM crop plants. This may be a useful strategy in some vegetable crops, in which the seed or fruit is not the harvested end product and flowers are not essential. But the trait would needs to be switchable in some way to allow production of seed by the seed producer and the breeding of new varieties by the plant breeder. Where flowers are produced, the technology already exists to produce flowers with infertile anthers. The use of male sterility is common practice in conventional commercial hybrid crop production and has been engineered into some GM varieties of oilseed rape. Where pollen is produced, a potential future technology could be to engineer GM plants with hybridisation barriers, either pre- or post-fertilisation. For example the production of pollen whose surface proteins are incompatible with those of the stigmas of potential recipient plants, preventing pollen tube growth and fertilisation of ovules, or barriers that cause seed abortion, through failures in endosperm development.

Eliminating or reducing bee visitation of GM crop plants is another possible strategy for minimising the dispersal of genes from them. Some plant species have breeding systems with potential for future engineering into GM crop species to prevent or minimise the likelihood of cross-pollination by bees. Apomictic species, for example, the dandelion, produce seed without fertilisation even though bees may visit them and deposit pollen onto their stigmas. The processes underlying apomixis can already be genetically manipulated. Apomictic GM plants could be made male sterile without compromising seed or fruit production. Cleistogamous species, like some lupins, have flowers that never open, discouraging bee visitation. Self-pollination occurs and pollen is unlikely to escape. This system could also be exploited or engineered into new plant species. Alteration of the reward (nectar and pollen) quality, flower shape, colour and scent also have potential for modification to reduce bee visitation of transgenic plants. Key genes controlling floral development have recently been isolated and their manipulation in crop plant species may enable these traits to be controlled. However, changes in the flowering patterns and pollinator visits to crops may themselves have undesirable impacts on the diversity of insects and birds in agroecosystems which will need to be evaluated in risk assessments. Any technological advances that reduce the amount of pollen and nectar available to bees, particularly in widely-grown crop plants could have far reaching consequences for the viability of bee populations, crop pollination and beekeeping.

Effects on non-target organisms

Effects on non-target organisms, such as bees, are also an important part of the risk assessment of GMO releases. Questions asked include: will bees visit the GM release for pollen/nectar/honeydew?, are new proteins expressed in the pollen or nectar ?, is foraging behaviour affected ?

Pollen grains are essentially tiny packets of genes. Genes consist of specific sequences of DNA nucleotides, or base pairs, which code for the structure of proteins or RNA. The full code is called a genome and most plants have about 20,000 genes in their genome. Gene expression is under the control of promoters, DNA sequences that regulate gene expression. A gene is considered to be active (switched on and expressed) when it produces a gene product (protein or RNA) and inactive (switched off) when it does not produce any products. If there is no gene expression in the pollen, it will not contain new protein, and is considered safe for bees (and man). If there is gene expression then applicants for any release must present the results of tests to demonstrate that any gene product is not likely to be toxic to bees (or man).

DNA alone is not toxic to bees (or man); biochemically there is nothing uniquely special about GM DNA compared to any other DNA. A single plant cell contains 10^{10}-10^{12} base pairs of DNA and most food crops contain about 0.02% DNA (by weight dry matter). In the gut, digestive enzymes break down the DNA into small fragments (<1000 base pairs), less than the size of functional genes. The Royal Society (1998) found ‘no evidence for the transfer of intact plant genes to the cells of humans or animals either from bacteria in the gut or from foodstuffs despite daily consumption of DNA in the diet’. Horizontal gene transfer from plant material to gut micro-organisms is considered to be a rare possibility and is a cause for concern where antibiotic resistance genes are used as markers in genetic engineering. Potentially, antibiotic resistance from pollen ingested in honey could be transferred to gut bacteria, leading to bacterial infections becoming resistant to antibiotic treatments. To avoid this possibility, the use of antibiotic marker genes is to be phased out under the new EU Directive 2001/18/EC by 2008.

GM plants that have been modified to be resistant to insects are the ones most likely to affect bees. These are being modified to contain Bt toxin (natural toxin produced by the bacterium *Bacillus thuriengensis*), proteinase inhibitors, lectins, amylase inhibitors or cholesterol oxidases and have potential to reduce insecticide application (Schuler *et al.*, 1998). Bt cotton, maize and potatoes are already being grown commercially in the USA and Australia and Bt maize is being grown in Europe to protect against attack by the European corn borer. Although the Bt toxin is expressed in the pollen of Bt maize, it appears to have no direct effect on bees (when fed to young larvae). Oilseed rape plants, modified to contain proteinase inhibitors (PI) in their leaves, do not contain PI in their nectar or pollen. Proteinases are enzymes that split proteins into peptides and the inhibitors thus target insect digestive enzymes. Tests have shown that bees do not distinguish between PI and non-PI rape in a flight room. When fed exclusively on PI in honey solution for 15 days, there was no effect on life span or on learning ability until the dose tested was 100 times that found in the leaves; thus although some effects from the toxin fed direct were detectable, bees would not normally ingest it.

Consents for release of GM crops are only issued when the risks to human health, including potential allergenicity of newly introduced proteins, and to the environment are considered to be low; frequently risk management and monitoring procedures post-release are imposed as conditions of consent. There is no evidence to date from the extensive growing of GM crops in the EU or in North America of harm to bees.

Farm Scale Evaluations

Throughout Europe, there is concern about longer-term environmental effects of the management of commercial cultivation of certain GM crops, particularly those expressing herbicide tolerance. Herbicide-tolerance genes code for plant enzymes capable of detoxifying a specific herbicide. The concern centres on the possibility that these crops will encourage higher levels of weed control which, in turn, would reduce invertebrate and bird numbers. Conversely, their use may allow early application of herbicide in the season, result in better crop establishment, permit an overall reduction in herbicide use and greater toleration of weeds (potential bee forage) under the crop canopy and at field margins.

In the UK, the Government is funding a 'Farm Scale Evaluations' (FSE) research project to examine whether there are any damaging environmental consequences from growing GM herbicide-tolerant crops on a field scale. Four GM herbicide-tolerant (HT) crops are involved in the trials: winter and spring oilseed rape, beet (fodder and sugar) and forage maize. In all, between 60-75 fields, varying in size, from 4 to 30 ha, are to be planted for each of the four crops. Each field is split into two, one half being sown with a GMHT crop and the other with an equivalent non-GM variety. These crops have already been evaluated in the laboratory and in small releases for their safety and approved by the regulatory authorities. This programme aims to determine whether the herbicide management associated with the crops, compared to that of non-GM crops, has any effects on farmland biodiversity. The farmers manage the crops using normal farming practices, treating the GM crop, if necessary with the herbicide to which its modification has made it tolerant. During the growing season of the crops, scientists are counting the numbers of weeds and key indicator insects, including bees (three times per year), in both the GM and the non-GM side of the field and in the field margins. Bees will visit the flowers of all the four crops in these trials. Studies are also being undertaken to measure gene flow between the two halves of the fields by collecting pollen and seeds, from the GM crops to wild relatives 10 m from the field and to more distant sites. Commercial planting of GM crops will not take place in the UK before 2003, at the earliest, after the results of the FSE have been published.

Bee Products

Safety

Where GM crops providing nectar and pollen are grown within foraging range of honey bee colonies, the bees will probably collect nectar and pollen from the crops and the bee products (honey, comb pollen, pollen from pollen traps) harvested from the colonies by the beekeeper will probably contain GM pollen. GM pollen from herbicide-tolerant oilseed rape has been detected in honey from colonies sited 2.5 miles (4 km) from an FSE trial site. A 10 g sample of floral honey, centrifugally extracted from pollen-free combs, typically contains 20-80,000 pollen grains (Sawyer1988); consumers are therefore unlikely to ingest more than picogramme quantities of protein from this quantity of honey. In 1991 and 1995, the ACNFP of the UK, considered the safety of pollen from GM plants in honey and concluded that the ingestion of protein from pollen in honey was likely to be very small and did not give rise to any health concerns.

Marketing

Marketing honey containing GM pollen, however has its problems, not because it is unsafe for human consumption, but because of public concerns about GM foods and the wish of a sector of the public to completely avoid foods with ingredients derived from GM crops. The adventitious presence of GM presence in honey threatens the perceived integrity of the product as a 'pure, natural and health-giving' food.

In response to consumer demand for GM-free foods, many supermarkets removed GM ingredients from their products in 1999. Similarly, the Honey Association, which purchases, packs and sells honey from UK and abroad, insisted that honey it purchased should be GM-free. However, there is currently no legal definition of GM-free. Further, there is no EU or UK legislation at present specifically relating to the labelling of foods as GM-free. However, the Food Safety Act of 1990 makes it an offence to describe, by way of labelling or advertising, a food falsely, or in a way to mislead a purchaser as to its nature, substance of quality. Further, the Trade Descriptions Act of 1968 makes it an offence for a trader to supply food with a false trade description or to which a trade description has been applied which is misleading to a material degree. Thus honey labelled as GM free and found to contain GM material would be in breach of this legislation. Unfortunately, tests for GM pollen in honey indicate either presence or absence (below the level of detectability) and not the quantity present and are expensive for individual beekeepers (*ca.* £85).

To meet supermarket requirements and to avoid the prohibitive costs of testing honey for GM content, the Honey Association advises beekeepers to site their hives at least 6 miles (9 km) from FSE sites. This is based on Soil Association rules for organic honey and the current view that products from the FSE trials should not enter the human food chain. This is inconvenient and costly for the beekeeper and causes conflicts where he has pollination contracts close to FSE sites. Furthermore, when GM crops become commercialised and more widely grown, it will become increasingly more difficult to site colonies 6 miles from them. Oilseed rape is grown on 8% of arable land in UK, is highly attractive to bees and the most important bee forage crop for them (Williams, Carreck & Little, 1993). Economic impacts of GM crops on organic farmers, non-GM farmers and beekeepers are not part of the regulatory procedure for 'safety' evaluation of GM crops. Liability for any GM 'contamination' of honey has not been resolved and beekeepers are not compensated for the extra work and expense of moving their hives. Avoidance by beekeepers of GM crops also has environmental implications for the pollination of GM crops, non-GM crops and wild plants within areas thus depleted of bees.

Labelling

Consumers want to know what they are eating, so there is public support in EU for labelling food with a GM content and the European Commission has responded with a serious of Directives and Food Regulations.

Regulation EC 258/97 provides for a statutory, pre-market safety assessment of all Novel Foods, including those from GM sources. It does not consider the means of production but only the content of the end product. It requires that all foods containing GM material (novel DNA or protein) in the final product should be labelled as such. The current EC view is that honey containing pollen does not constitute a novel food and is therefore not subject to the labelling requirements of the Regulation. But there are no specific exemptions for pollen as a food so pollen marketed alone as a food or food supplement would be subject to the range of food labelling regulations currently in place.

Regulation EC 1139/98 came into force in 1998 and requires products to have a GM label if they contained novel DNA or protein from GM soya or maize. In 2000, Regulation EC 49/2000 established a *de minimus* threshold of 1% for the adventitious contamination of a non-GM product, requiring no GM label if the contamination was under this threshold. The level of GM pollen in honey is unlikely to exceed this amount. Regulation EC 50/2000 requires foods and food ingredients to be labelled where they contain additives or flavourings containing or produced from a GMO, but only where DNA or protein from the GMO is detectable. The EU is currently revising its labelling directives. Some Member States, appear to favour labelling as a GM product even one that contains no modified DNA or protein in the final product. The Honey Association (UK) has stated (August 1999) that it intends to label any honey found to contain GM pollen as containing GM material.

Traceability

'Traceability' can be defined as being able to ensure 'the retrieval of the history and use or location of an article or an activity through a registered identification (ISO Standard 8402). The new EU Directive seeks to establish a system of traceability for GM products by assigning a unique identifier code to each GMO that receives consent for commercial release. Each code together with information about the GMO will be recorded on a central register maintained by the EC. Some Member States are futher demanding that this system should cover not only 'live GMOs' but also products derived from GMOs but containing no viable GM protein or DNA (eg refined oils).

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