Although it is still challenging for certain species such as wheat, many crops can be routinely genetically modified. During the early to mid-1990s, the research translated into commercial reality, and transgenic crops such as tomatoes, soya and cotton were available in several countries. Outside research, commercial and regulatory circles, the production and consumption of transgenic crops attracted little interest and relatively limited controversy until 1997. However, between 1997 and 1999, the issue rose to prominence in the popular media, and to a key issue of social debate in Europe, Australia and many other parts of the world. Central to the debate on genetically modified foods is the safety of genetically modified crops and their potential environmental effects, and whether mankind, especially developing countries, can secure the benefits of genetically modified crops while most effectively avoiding any risks they may present. The major issues raised by those opposed to genetically modified crops are undetected effects on human health, a myriad of potential environmental effects and a less definable sense that genetically modified crops are unnatural. Issues that follow are labelling of genetically modified foods (whether to label, which genetically modified products to label and whether such labelling should be voluntary or compulsory), and whether labelling should be backed up by testing. This review discusses the scientific and commercial motivations for development of genetically modified crops, current applications of the technology in the context of the debate on safety concerns. The focus of much of the debate has been developed countries such as Europe, but it is possible that the technology could have the greatest utility for developing countries.

Introduction

Genetic engineering or modification of crops or modification can most simply be defined as the transfer of genetic material from a different species (plant, bacterial or animal) or from a chemically-synthesized gene into a target plant. The first successful genetic engineering of a plant was reported in 1983. Broad-leafed plants such as tobacco and tomato were easiest to transform, and reliable transformation of cereals such as rice and maize were not reported until the late 1980s. Reliable transformation of barley and wheat only commenced in the mid-1990s. Genes (as parts of chromosomes rather than individual genes) have been spontaneously transferred from grasses such as *Agropyron* into wheat and the derived varieties used for human food with no controversy. Other techniques such as use of plant tissue culture, induced mutations, doubled haploids and F1 hybrids also involve interference with natural breeding but have not raised controversy. The distinguishing feature of genetically modified plants is the targeting of the genes to be used and the fact that the target gene is not restricted to being in the same species. Indeed, the potential to be able to use human or animal genes in plants was earlier utilized by scientists as an example of the potential of the technology. However, it is likely that use of these examples had negative impact on public perceptions of genetic engineering.

Applications of crop genetic engineering

The balance of genetically modified crops that are grown on a commercial basis has changed significantly in the last 2 years, with soyabean and maize now dominating, in the mid-1990s major crops were cotton, tobacco and tomato. There are currently 12-15 major genetically modified crops produced world-wide, but many more are at the development stage. The main commercial or near-commercial applications of crop genetic transformation are:
Transformation for insect resistance

This is important in field and horticultural crops as well as plantation trees. Of the transgenes used, the most common modification involves use genes for protein toxins (termed Cry IA and Cry 2Aa) from the soil bacterium, Bacillus thuringiensis (Bt). The Bt plants are insecticidal to a limited range of specific caterpillars and beetles, but they are often the pests of major commercial significance; in the US this includes European corn borers (Bt maize), bollworm and budworm (Bt cotton) and Colorado potato beetles (Bt potatoes). Another example is transformation of peas with a kidney bean amylase inhibitor gene to develop a source of resistance to pea weevils. A cowpea gene has also been used in strawberries to confer weevil resistance.

Transformation with desirable quality genes from other plants

This can be important for both food and feed production, although it remains a minor application of crop genetically modified thus far. The first quality-enhanced product on the market were tomatoes containing a lower level of the product of the polygalacturonase gene. The lower activity of this enzyme means that the long pectin chains in the cell walls of the fruit are cleaved more slowly and the ripe fruit does not soften as quickly, thus extending its shelf life.

Oil content and composition are important, with high oil soybeans and modified canola (oilseed rape). The transfer of a thio-esterase gene from a bay laurel tree to canola has led to the development of high lauric acid in oil (by preventing the synthesis of longer chain fatty acids), useful for raw materials in detergent manufacture. Prevention of damage-induced browning, usually by blocking genes for polyphenoloxidase (and possibly peroxidases) is a significant application in a diverse range of horticultural crops: potatoes, apple, lettuce, pears, bananas, grapes and pineapple. Alteration of processing properties in cereals such as enhanced levels of amylolytic enzymes for degrading starch for barley brewing and increased levels of glutenin flour proteins to alter dough properties in wheat. Among animal feed grains, lupins have been transformed with a sulfur-rich gene from sunflower seeds. The high sulfur animal feed grains provide enhanced wool production in sheep and meat production in a range of animals.

Transformation for disease resistance

Transformation for virus resistance is especially well developed; transgenic plants containing various parts of the viral genome can be protected against the virus. This includes, but is not limited to, expression of coat protein genes in the target plant. There are many successful examples of this principle: tomatoes and tobacco resistant to tobacco mosaic virus, potatoes resistant to potato leaf roll virus (PLRV), white clover resistant to alfalfa mosaic virus. As the natural disease resistance genes of plants are being better cloned and characterised it is likely that they will also find use in transgenic plants. An indirect, but powerful, way of enhancing virus resistance is through engineered aphid resistance, as these are carriers of viral diseases in many crops such as potatoes and tomatoes.

Transformation for herbicide tolerance

By making a target crop resistant to a herbicide, control of difficult weeds can be improved, increasing yields and lowering inputs such as labour and fuel for cultivation. The major transgenic herbicide-resistant crops are maize, soybeans, cotton and canola, although several more are under development. Herbicide-tolerant pastures, such as subterranean clover enable farmers to control broadleaf pasture weeds earlier in the growing season and with low levels of herbicide. Major herbicides are broad-spectrum ones such as glyphosate (Roundup) and glufosinate (Basta). Glyphosate normally inhibits an enzyme (enolpyruvyl shikimate phosphate synthase, EPSP) of (essential) aromatic amino acid synthesis; however, resistance can be obtained through transformation with a glyphosate-insensitive EPSP from Salmonella bacteria. Resistance to glufosinate is instead derived by transformation with an enzyme that inactivates it (phosphinothricin acetyltransferase, PAT) from various Streptomyces bacterial species. Similarly, resistance to bromoxynil can be obtained through transformation with a specific nitrilase from Klebsiella bacteria.

Transformation for agronomic performance

It has often been said that the three most important characters of a crop to a farmer are yield, yield and yield! Indeed, some of the major returns from genetically modified crops thus far have come about because their use has allowed management strategies that optimise yield. However, there are few commercial transgenic crops that inherently have been designed for yield improvement. This area is an active area of research because of the importance of factors such as stress tolerance and water use efficiency. However, modified soil bacteria, which enhance nitrogen fixation by crops have been widely used in certain countries, including China. Some specialised agronomic modifications, such as cold tolerance in strawberries (using an arctic flounder fish antifreeze protein gene) have already been commercialised. Ornamental crops such as cut flowers are also being manipulated. An carnation, engineered by using a gene from petunia has created a new colour (blue-purple) has been developed in Australia and on the market since 1996. In addition, senescence delay can prolong vase life.

Transformation for nutritional or pharmaceutical purposes

Examples include enhanced lysine content in maize, and enhanced vitamin A content in canola. However, edible vaccines for viral and diarrhoeal diseases using proteins expressed in transgenic plants is an application of potentially huge significance for developing countries. The vaccine is expressed in edible parts of fruit, vegetable, grain plant, and has several potential advantages. Multiple vaccines could be produced in one plant (e.g. to all hepatits strains). They could be delivered at a lower cost for developing countries, as they do not require purification. Administration is more user-friendly, and there is no risk of contracting other diseases from dirty needles. The vaccines do not require a health care professional to administer and will not require refrigeration prior to use. Edible vaccines to viral hepatits in humans and to swine transmissible gastroenteritis virus have already developed and are in clinical trials.

Impact in developed countries

The technology has had a major impact already. In 1998, 28 m ha was grown to transgenic crops world-wide, of which 74% was in the US. Another 15% was in Argentina, a major soyaabean grower, where about half of the soya was genetically modified (resistant to glyphosate). Canada has significant areas sown to transgenic crops (10% of world crop), and in Australia, a significant proportion of the cotton crop is transgenic. However, the areas of commercial plantings of genetically modified crops have been negligible thus far in Europe, although there were some plantings in Spain and France. US farmers in particular have found some immediate economic benefits. With herbicide-resistant genetically modified soya, post-emergent herbicides have been able to be used. The benefits however have been far greater than savings in weed control since the retention of soil moisture from a lack of disturbance have significantly increased yields. With cotton, the cost savings are several; reduced pesticide use and a cleaner product entering the cotton gins has also saved processing costs.
The most quantitatively important factors are currently herbicide tolerance and insect resistance, followed by virus resistance. Despite delayed ripening “FlavrSavr” tomatoes being the first commercial genetically modified crop in the USA, quality improvements are of still only rather minor importance. This may be for both technical reasons (genes associated with product quality are often hard to characterise) and commercial reasons (farmers are less sure of getting premiums for quality than they are for lowering inputs of increasing yields).

Potential impact in developing countries

It is often forgotten by Western scientists and policymakers that China, and not the US, was the first country (in 1993) to grow transgenic crops on a commercial scale, virus resistant tobacco and tomatoes. China is now only a relatively modest producer of Bt cotton; the proportion of genetically modified crops in China as a proportion of those world wide is decreasing. This is not due to Government influence in China, but rather because seed distribution and vertical integration of seed sales through to crop marketing are far better developed in the West.

From a technical standpoint, the use of crop genetic modification could have substantial benefits for developing countries. These may include increased disease and pest resistance, increased yields, crops with higher nutrient content and delivery of vaccines. Higher lysine maize and bananas carry vaccines have already been engineered. There is potential, as yet unrealised, for genetic engineering to assist those in developing countries who did not benefit from the “Green Revolution”, especially farmers in rainfed marginal lands. Genetic engineering could enhance the ability of crops to be resistant to soils with high levels of salt, acidity or toxic elements such as aluminium or boron. Drought resistance is a difficult phenotype to manipulate, but advances are being made in conventional breeding and in some cases gene identification. For example, the international wheat and maize centre, CIMMYT has recently made significant advances using conventional breeding in developing drought resistant maize genotypes. Genetic engineering has the ability to enhance the ability for legumes to fix atmospheric nitrogen with the potential for crops such as cereals to also fix nitrogen. This would decrease the need for often expensive and imported fertilisers. Enhancement of storage qualities and transportability of perishable crops through genetic modification could be especially important for developing nations.

However, the main benefits in the major crop, rice, could still lie ahead, with rice blast resistance, stem borer resistance using Bt and herbicide tolerance being actively developed. Rising rice demand will not be met because of limited rice cultivation areas and rapid population expansion. Dr Ronald Cantrell, Director-General of the International Rice Research Institute, estimated that by year 2025, the population in Asia will increase by 1-1.5 billion and need 60% more rice than in 1995. Bt rice, developed through the Asian Rice Biotechnology Network underwent major field trials in China in 1998. Currently $1000 m annually is spent on insecticidal control in rice in Asia alone (Krattiger, 1997). One of the greatest challenges will be in delivery of the technology to developing countries since there is often a poorly-developed seed industry. However, the fact that “Green Revolution” cereal varieties were relatively rapidly adopted in an era when infrastructure and transport were poorer is encouraging for future seed distribution.

But are the crop genetic improvements that are currently available suitable for developing countries? There are wider issues than the obvious one that most of the species being engineered are temperate, Western crops rather than crops such as cassava. Recently, sweet potato, a developing country crop, was engineered for improved protein quality (Moffat, 1998). A worrying prospect for developing countries is that some of the products of genetic engineering have the potential to displace crops in which developing countries currently have lucrative export markets. For example, coconut oil is naturally high in lauric acid, useful for soaps, detergents, margarine and cooking oil. It is especially central to Philippines agriculture, but is also important in Indonesia, Malaysia and India. Its major competitor, palm oil, is central to the Malaysian economy. However, both are now under challenge from high-lauric acid transgenic canola oil (Murphy, 1996), and canola is suited for growth in temperate developed countries, genetically modified crops that require capital investments such as aerial sprays and irrigation and/or may reduce labour needs could have poor adoption and fuel unemployment in developing countries. Other concerns include that the cost of accessing the technology may be too high, as genetically modified crops are one of the greatest areas of commercial involvement in agriculture, and are dominated by US- and European-based multinationals. There are also broad patents (broad in both the terms of technology covered and geographical coverage) granted to these multinational companies. These not only cover specific crop products, but enabling technologies such as use of Agrobacterium vectors for transformation. Developing countries may not have access to technology at affordable prices. Several of the multinationals are reluctant to operate in developing countries as they perceive that their intellectual property may not be sufficiently secure. More importantly, biotechnologists in developing countries scientists in they may have their freedom to operate taken away.

There is thus a rather spirited debate on whether genetically modified crops will contribute to food security in developing countries or lead to food insecurity, and many of the same public acceptance concerns remain valid (Aerni, 1999). In addition, is crop genetically modified appropriate technology for developing countries or should the focus be on standard breeding, agronomy and extension to improve yields, quality and reduce postharvest losses? The inability to re-sow seed in many of the commercial contracts established in the west is of particular concern. Terminator technology (more correctly known as Gene Use Restriction Technology (GURT) refers to a set of genetic switches that can be activated in transgenic crops to ensure that the grain is not useful as seed. While this is intended to ensure that the purchaser of the technology cannot avoid paying for its potential advantages through regular purchase of seed, it commits the farmer to regular outlays that may not be achievable. It is of interest that the Consultative Group for International Agricultural Research (CGIAR) and several other international groups have criticised GURT from an ethical standpoint, and banned its use in CGIAR breeding programmes (CGIAR, 1998). While it can be argued that the technology has advantages in preventing escape of transgenes to wild relatives, a starving developing country farmer could not re-sow their seed in a famine year.

It is fair to say that this debate is still active within many R&D organisations in developing countries and within donor agencies such as the my own, the Australian Centre for International Agricultural research (ACIAR). There are six current ACIAR projects with a focus on crop genetic manipulation. We are investing in genetic engineering at the request of particular developing countries, often for manipulation of traits that are of major importance but are unable to be modified by conventional plant breeding: for example, “black-heart” in pineapples. We also view it as a capacity-building exercise for our partner scientists, to enable more considered technical and policy decisions to be made. However, the vast majority of our Crops Programme portfolio is still in the traditional areas of agronomy, breeding and postharvest technology, as well as biological control and integrated pest management.
Several developing countries have active genetic engineering research in their national programmes, but international initiatives should prove to be of immense benefit. While several of the CGIAR (Consultative Group for International Agricultural Research) centres have active programmes on genetic engineering of their target crops, some other centres have a special focus on the broader issues of training and safe use of plant biotechnology. The ICGEB (International Centre for Genetic Engineering and Biotechnology) have a focus on research and training in molecular biology and biotechnology, emphasising developing country needs and safe use of biotechnology. IFPRI (International Food Policy Research Institute) carries out research on the implications of biotechnology and biotechnology policy for poverty alleviation in developing countries. ISNAR (International Service for National Agricultural Research) works with developing country national systems to provide training in intellectual property management and biosafety. ISAAA (International Service for Acquisition of Agri-biotech Applications) plays an important role in assisting developing countries to identify biotechnology needs and potential impacts (Krattiger and Rosemarin, 1994). They monitor and evaluate the availability of biotechnology, including genetically modified crop technology, for transfer to developing countries. They focus on horticultural crops (as there are economic structures that can absorb the higher-value commodities), non-commercial crops grown by poor farmers, and forestry. Importantly, ISAAA brokers the donation of transgenes from multinationals and universities to developing country partners – for example donations by, potato virus control in Mexico (Monsanto); cucumber mosaic virus in Costa Rica (Asgrow); papaya ringspot virus resistance in Thailand and South America (Cornell University). The ISAAA have also played an important role in working with countries such as Indonesia, Malaysia and Thailand to implement regulatory mechanisms for genetically modified crops.

The Rockefeller Rice Biotechnology Program has a focus on developing tools in Asia for rice genetic mapping, marking important genes and establishing rice transformation capabilities in developing countries. They have commissioned CAMBIA (Centre for Application of Molecular Biology in International Agriculture) to develop a database which will indicate the ownership of technologies, an important issue in determining whether scientists in particular countries have “freedom to operate” in manipulation of certain crops. BINAS (Biotechnology Information Network and Advisory Service) is an information initiative of UNIDO (United Nations International Development Organization). It also serves as a central clearinghouse for information of biotechnology regulations in different countries.

Safety concerns – genuine or perceived?

Ethical issues

A major concern that is expressed regularly in public surveys and the media is a perception that crop genetic modification is an unnatural, insufficiently-triailed technology. Some groups argue whether there is a need to take any risks that are not necessary, and that the future security of the food supply of at least developed countries does not have to include genetically modified foods. This is basically a conservative argument that could be used, for example, to stop the release of new pharmaceuticals. However, there is a clear difference between safety evaluation of a new drug and of a transgenic plant species. If a drug is found to have unexpected and unacceptable side effects, manufacture can be ceased and it can be withdrawn from the market. As living self-propagating organisms, genetically modified plants cannot be “recalled” in the same manner.

Genetically modified crops do bring together new gene combinations that do not exist in nature, and this fact is the basis of some of the reservations of those opposed to genetically modified crops. An additional reservation is that the application of biotechnology to food unnecessarily makes it an “industrial commodity”. Public confidence on food safety in developed countries has been undermined with bacterial food poisoning outbreaks in the US, “mad cow” disease (bovine spongiform encephalitis, BSE) in the UK as well as dioxin contamination recently in Belgium. There is decreasing trust in Government’s ability to regulate, especially as in the interests of small government, many of these responsibilities are being handed to the private sector to self regulate. Also, much of the research on crop biotechnology is carried out and commercialised by multinational companies, with accompanying consumer mistrust of their motives.

Often the differences between a conventional approach in agriculture and use of a genetically modified crop are in practice minimal. For example, one of the most common modifications in genetically modified crops is the expression of Bt toxin, which is especially toxic to caterpillars, in the leaves of the genetically modified plant. Bt toxin has been applied by farmers, including “organic” ones, as a safe pesticide for some years.

Religious reasons and cultural issues for avoiding genetically modified foods may be more important in developing countries compared with the secular West. Certainly views differ, but many religious leaders, including those of orthodox Judaism have expressed acceptance of genetically modified crops. A fish antifreeze gene in a plant is no more than a stretch of DNA – there is no lingering association with a fish in the genetically modified crop, but what are the perceptions of many vegetarians? Without labelling, it is true that there is a loss of individual control over what an individual is eating, and that it is appropriate to maintain a freedom of choice. Such a choice can either merely acknowledge a diversity of views of allow people to feel safe by avoiding them. The interest of the consumer in choosing the food they eat is especially the case when consumers are presented with a product that offers them no benefits e.g. genetically modified soya, where the benefit is designed to be captured by the farmer rather than the consumer. A much larger proportion of consumers would be willing to support crop engineering if there were more obvious benefits to them such as tastier or cheaper food, or produce that is less prone to spoilage.

A final source of concern regarding genetically modified crops is that they represent the industrialisation of agriculture. This may be seen as a somewhat romantic view in the West. Over the last 100-200 years, agriculture has become more of a business, with larger farm sizes and farm populations decreasing. Commercialisation and vertical integration of agribusiness and “closed loop” marketing of seed purchases with crop sales can merely be seen as a continuation of a long-term trend. However, industrialisation is a very genuine concern for developing countries, especially small-holder agriculture. There is concern that higher costs of genetically modified crop seed technology may place it out of reach of developing country farmers, especially when combined with marketing agreements that ban the saving of harvested seed for replanting. There are only six major groups of companies that own most of the enabling patents to enable them to undertake genetic modification of crops. With some herbicide-resistant crops, the multinationals (former agrochemical companies, now biotechnology companies) may hold patent control over both the seed of the herbicide-resistant transgenic crop and the herbicide.

Risks for human and animal health

Many of these concerns were highlighted over a number of media reports in 1998 of possible negative effects reported in a trial by Dr A Putzai of the Rowett Institute in the UK, on growth and immune...
function of rats fed genetically modified potatoes containing a lectin. Although there is still some controversy over these results, they have been discounted by many scientists since lectins are known to have specifically bind certain cell types and exhibit toxic effects; the fact that the genetically modified food containing the lectin had a similar effect to direct feeding of a lectin is hardly surprising.

The use of other plant species as gene sources can bring the risk that unexpected allergens could be present in genetically modified foods, while there is no threat of allergy in the unmodified crop. One complication in assessing this risk is the variable nature of plant-food allergy between individuals and between species. In some plants such as rice and certain nuts, there are 1-2 very well characterised proteins that are particularly allergenic (allergy-inducing). An early programme focussed on increasing the sulphur amino acid content of transgenic soybeans by introduction of a high-methionine brazil nut gene was technically successful, but terminated by the company developing the crop since problems of allergenicity were established with the transgenic soya through detection of a strong antibody response in allergic individuals (Nordlee et al., 1996). However, it does not follow that, for example, engineering of other rice or peanut proteins into say maize would cause ill effects if a rice or peanut-allergic individual consumed the maize. The issue is further complicated in other species such as wheat where several proteins contribute to allergy and food intolerance and among allergic individuals, there is evidence of individual-to-individual variation in which proteins are most toxic to them. Since in many cases there are extensive amino acid sequences databases of known allergens, genes for consideration for use in food crop transformation are assessed against this database. In addition, other in vitro tests using sera, mast cells or lymphocytes of known allergic individuals can be carried out. Feeding trials with human subjects are a possibility but they have many drawbacks, especially if any negative effects of a food are slow and chronic rather than acutely detectable. Another issue is that while it is possible to test the toxicity of drugs in animals at say, 100–1000 times normal doses, this is hardly possible for a major dietary component! At best a comparison of animals on diets containing the same non-genetically modified and genetically modified crop can be made (MacKenzie, 1999). New combinations of gene products, with the potential of novel interactions between the transgene product and others within the wild type crop have been suggested as a potential source of allergy may or may not increase the risk of allergy. It is of interest that some labelling proposals of the EU provide special interest that some labelling proposals of the EU provide special consideration for the use of genetically modified foods that could contain allergens. On the other hand, there is an active programme in place in Japan to engineer rice varieties with reduced levels of particular protein allergens.

Antibiotic or herbicide resistance marker genes are often co-transformed to be used as a “selectable marker”, to facilitate the identification of cells into which the target gene has been successfully introduced. The use of antibiotic resistance genes had led to concerns about the possible risk of increased human and animal resistance to antibiotics through the food chain. The major marker used in plant transformation has been a bacterial gene for neomycin phosphotransferase (Npt II), which confers resistance to neomycin, kanamycin and puromycin. Of these, only neomycin is used in plants. It is most relevant where a crop has weedy relatives especially relates to the risk that herbicide resistance could lead to proliferation of resistant intestinal bacteria in the cattle if ampicillin was used in their feed. There was considered to be a remote but real chance of the resistant bacteria infecting humans in contact with the cattle. Alternatives to marker genes such as use of natural enzyme systems, including enzymes that are not normally found in untransformed plants but found in other food species, or use of a green fluorescent jellyfish marker protein may be more acceptable. There is an international push to either remove the selectable markers after transformation (although still difficult technically) or to not use them now that the transformation efficiencies of many crops is becoming higher.

Environmental pollution

One of the major classes of genetically modified crops involves engineering of specific herbicide resistances into the food or fibre crop, to allow use of broad-spectrum herbicides such as glyphosate in the standing crop. This allows the use of the otherwise toxic herbicide in the growing crop to minimize weeds, which are competition for the yield of the crops. There are concerns that this will encourage increased use of herbicides with potential for higher residues in food and the environment. There is some validity in this argument, although the evidence for chemical residues becoming higher in major crops is scant. Herbicides such as glyphosate have negligible human toxicity (less than table salt) and because they bind to soil do not get transferred to harm native vegetation these shorter acting herbicides are less persistent than the alternatives needed for weed control in non-genic crops. Indeed, use of herbicide-resistant crops can actually decrease the amount of herbicide used because spraying can be done as needed rather than routinely at sowing in anticipation of weed problems. It is also important to realise that introduction of other transgenic crops, e.g. Bt crops, has lead to a significant reduction in the use of chemical insecticides. Other genetic modifications to plants can also reduce environmental contamination. For example, paper from genetically modified poplar trees (with decreased lignin content) will need less bleaching.

A second concern relates to damage to non-target insect species (including beneficial insects used in integrated pest management programmes) by insect-resistant crops. A series of 1999 reports (Losey et al., 1999) suggested that pollen from Bt-modified corn was injurious to the larvae of monarch butterflies in a laboratory situation. The results have, however, been criticised on several grounds. Bt was already known to kill Lepidoptera caterpillars, very large amounts of pollen were fed to the larvae in the experiments and no dietary choice was provided for the caterpillars.

Concern about the escape of transgenes to related, native plants, such as wild relatives especially relates to the risk that herbicide resistance may escape to weedy relative species (Arriola, 1999). It is also important since the herbicide resistances most used in genetically modified crops are ones such as glyphosate, widely efficacious for broad-spectrum weed control. However, the chances of such spread are reduced by several factors. The crop and weed would have to flower at the same time, a pollen vector (insect, wind) would need to carry the pollen and the crop and weed species would need to be sexually compatible and capable of producing fertile progeny weed plants. It is most relevant where a crop has weedy relatives with which they can breed; canola (Brassica napus) and squash (Cucurbita pepo) are key examples.

Herbicide resistance is not the only concern. Natural population of wild relatives of Brassica and melons are kept in balance through virus load. It is possible that transgene escape could allow either the evolution of new viral types or alternatively alter the structure of wild plant communities. Some approaches to minimise this risk are
to use the recognised standards for avoiding spray drift of chemicals for avoidance of pollen drift of genetically modified plants. Use of unrelated surrounding trap crops is also valuable. It is clear, however, that the risk of outcrossing of genetically modified crops to wild relatives is real for certain crops, and is best considered on a crop by crop basis (Sindel, 1997). New transformation technologies, such as chloroplast transformation, may also limit the risk of transgene escape, since pollen carries nuclear rather than chloroplast genes.

Escape of transgene to micro-organisms is an issue of potential concern, especially with antibiotic resistance marker genes. However an evaluation by WHO (WHO, 1993) did not conclude that it was a significant risk. In contrast in 1999, the UK ministerial advisory body, Advisory Committee on Novel Foods and Processes did determine that transfer of such genes to gut micro-organisms could be significant. Antibiotic resistance is only an advantage when there is positive selection (i.e. cells are in the presence of the antibiotic); this is unlikely in field situations. On other occasions, the presence of the resistance genes can often decrease the relative viability of the bacteria.

**Risks to agricultural production**

There have been a number of concerns in this category. Some authors have suggested that crop plants could become weeds or superweeds due to enhanced fitness and herbicide resistance. Alternatively, transgene escape to “non-engineered” crops of the same or related species through pollen or seed dispersal could occur. Maize pollen can travel long distances by the wind. The UK government has established a 200 m barrier around genetically modified crop trials. A compromise may be to surround genetically modified crops with other species. Pollen from self-fertilising genetically modified crops, such as canola are less to fertilise non-genetically modified canola, since “foreign” pollen competes poorly with the pollen from the same plant. Despite concerns of some consumer and media groups, there is no evidence that DNA consumed in the diets of humans or animals can be transferred to incorporate into host chromosomes, especially given that we consume many thousands of different genes daily in our diet!

Some seed companies are concerned that the investment in genetically modified crop development may be lost through instability of transgene expression, or development of resistance to transgene product. Certainly resistance can develop; for example The major source of resistance encountered with genetically modified crops is insect \textit{Bt} resistance (Krattiger, 1997). In the Australian cotton industry, this is being countered using established Integrated Pest Management approaches. \textit{Bt} cotton reduces, but does not eliminate the use of chemical insecticides her insecticides. In addition small “refuges” of attractant non-\textit{Bt} crops are also required to be planted near \textit{Bt} cotton, to provide a source of non-resistant target species (in this case \textit{Helicoverpa}) to prevent domination by a non-resistant population. Resistance problems have been common also in conventional agriculture. For example in the UK in the 1970s and Australia in the 1970s-80s, many wheat varieties were released with single major gene resistances. These resistances broke down rather rapidly and the life of some varieties was very limited. Breeders now “pyramid” multiple gene resistances to avoid the risk of loss of single gene resistance; a similar approach is now being followed with transgenes. A separate approach uses two separate transgenes in cotton to provide insect resistance. There are some reports of resistances to the herbicide targets used in transgenic herbicide-resistant crops, but of greater relevance may be whether longer-term use of herbicide-resistant crops will encourage the selection of resistant weeds (Gressel \textit{et al.}, 1996).

Another concern relates to the potential for commercial dominance of 1-2 varieties, leading to a loss of biodiversity. In many cropping and horticultural systems, growth of a variety of cultivars is encouraged. This can provide useful differences in maturity/ripening times, a range of disease resistances or a range of processing suitability. In contrast, many of the genetically modified crops are provided or distributed as a single cultivar. Often, released cultivars are found to have major unforeseen disease susceptibility, quality or agronomic problems. It is conceivable that farmers contracted to a company for production of a particular genetically modified crop could be encouraged to grow an agronomically-poorer variety so the company can recoup its R&D and marketing investment.

**Labelling of foods derived from genetically modified crops**

Even in the absence of hard evidence that genetically modified foods are less safe than unmodified foods, the argument that consumers have a right to know is persuasive. Labelling of foods or products from genetically modified crops would at first view appear to be a relatively straightforward option. It is not. The decision to introduce labelling involves technical, logistic and commercial considerations. The food and fibre products from genetically modified crops generally fall into two categories.

In the first, the products contain “foreign” DNA or protein and this can be tested for, by either targeting the DNA (and detecting the specific transgene product using sensitive diagnostic methods: either PCR or DNA profiling). Alternatively, proteins (and potentially other products such as flavours, colours) can be detected by immunoassays. These are less widely applicable than the DNA-based tests but when they can be applied they have the advantage of usually being simpler and less expensive to perform. Several companies have developed diagnostic tests using antibodies to \textit{Bt} toxins. Recently, some even simpler test formats, especially those based on immunonassay, allow for low-cost testing of certain crops, in field or non-laboratory situations. The main advantage of the latter type of test is that the cost of testing should be significantly reduced: $10-20 (including sample handling and reporting of results), rather than the several hundreds of dollars currently quoted by central laboratory services. The first of these tests are now on the market: for example, a disposable immuno-chromatography device available in the US (QuickStix™) can detect the Cry 1A and Cry 1Ac \textit{Bt} toxins engineered in \textit{Bt} maize and cotton crops. DNA-based testing is also becoming more widely available. DNA testing (using either polymerase chain reaction or restriction fragment analysis) is highly reliable with raw or lightly processed food, but cooking or processing can degrade DNA. The UK company, RHM Technologies is offering fee-for service DNA-based testing, using a newer test which is able to utilise smaller DNA fragments and is thus more reliable with cooked foods. While there is not an international consensus, many more groups are comfortable with requirements for labelling of foods which contain a detectable transgene or transgene protein product. The main issues will be knowledge of the gene sequences used and the public availability of the sequences (e.g. after publication of a patent) to allow the development of diagnostic probes. The testing situation will become more complex as food containing multiple genetically modified ingredients or using crops with pyramided transgenes appear. Another issue currently being debated is the threshold level for labelling of genetically modified foods e.g.: should a food only be labelled if it has more than 1-2% genetically modified crop content? There are a myriad of further issues related to labelling, many of which remain to be resolved. Should milk from cows feeding on transgenic pastures be labelled, even though the cows are “normal”? Should labelling only apply to foods at purchase
from markets or should restaurants be required to label their menus? All of these factors will encourage industry and the community to avoid using transgenic foods but perhaps for the wrong reasons. Soyabean is the crop posing most dilemmas with labelling. Soya in processed forms is used in breads, milk substitutes, flavourings, meat and meat replacement products, margarines and confectionery, as well as being widely utilised in animal feed.

However, because the food derived from some genetically modified crops is perceived as being no different from a food from an unmodified crop, and partly because of the difficulties of testing, many farmer and industry groups (and some governments such as the US) have adopted the term “substantially equivalent” and have not required labelling. “Substantially equivalent” can have a range of meanings, but often includes criteria such as:

- no substance is introduced that does not have a prior established history of safe consumption
- no substances introduced which may be offensive for religious reasons
- processing or preparation of the crop is no different to normal crops
- no decrease in nutritional value.

The second group of genetic modifications are more problematic. There is no test for products which originate from genetically modified plants but which do not contain modified DNA or proteins, such as refined sugar from genetically modified sugarcane or sugar beet. Labelling of these crops will require a clearly identifiable and audible food trail for identity preservation and certification of the chain of handling and processing of the crop, perhaps requiring duplication of production plant and equipment to separate genetically modified from non-genetically modified foods.

Labelling is certainly an extra impost on developing as well as developed countries. Consumer groups are loudest advocates of segregation but may not be willing to pay additional cost. Perhaps of greater concern of industry is that with current sentiments, consumers may be reluctant to purchase fresh or processed foods that were clearly labelled as genetically modified. Indeed, in 1998, there were large export sales of non-genetically modified canola from Australia to European customers who had difficulty sourcing non-genetically modified grain from North America. The right to know will probably encourage more governments to support or enforce labelling of genetically modified foods. With other food types, there is a general trend for consumers to demand more labelling of foods: for patients who suffer potentially fatal anaphylactic shock after consuming peanuts, coeliac disease patients who suffer diarrhoea and a heightened risk of intestinal cancers if they consume wheat, and of some migraine patients who cannot tolerate chocolate.

Labelling is thus an area of considerable public policy and political debate, and indeed is regularly evolving with developments in technology, trade and public opinion. Perhaps the last of these has been the most powerful: only 3–4 years ago the major UK supermarket chain, Sainsbury’s plc proudly promoted a house brand of tomato purée as being derived from genetically modified fruit, and the brand accounted for half of their sales of tomato purée in the UK. By early 1999, the tide of public opinion had turned so much that Sainsbury’s had withdrawn this and all other genetically modified products from their shelves.

Conclusion

This review has focussed on crops. It is also possible to genetically modify food animals, e.g. for faster growth, leaner meat content. Although there have been a number of commercial trials, the consumer resistance to manipulating animals (but not, apparently, fish) is much more widespread. While there are some environmental concerns, such as escape of transgenes to weedy relatives, there appears to be little threat to human health through consumption of the foods. There is a need, however ensure that safety as well as efficacy testing carried out and results are publicly available. There is also a need to ensure that the public debate is balanced; so often the opponents of genetic engineering use emotive arguments with little technical substance (e.g. terming them “Frankenstein Foods”). No longer are these views just expressed by the green movement or radical environmental groups but by major political parties and mainstream journalists. One main reason for the negative press is that most of the genetic modifications in greatest use thus far have been designed to have farmer and commercial benefits rather than consumer benefits. The tomatoes which can be processed more easily and provide a reduced cost to consumers have been already been accepted more readily than other genetically modified foods in the UK. Maybe as improvements such as plant-derived edible vaccines, foods that stay fresher longer and are tastier and more nutritious appear, consumer support will increase. Farmers themselves can move their production in and out of genetically modified crops. With cotton in Australia, when water or prices are low, many growers return to cheaper non-genetically modified cotton seed for plantings.

The author believes that the public pro-genetically modified food debate has been poorly managed. So often it is led and presented by scientists or business people, with accompanying suspicions in the general public of a science-push or profit motive. There is a need to utilise farmers or lay people in the argument. Farmers can explain the tremendous decline in their margins over the last couple of decades, so to make a living they need to produce much more food than before as real farm-gate prices for many commodities have dropped worldwide. With or without genetically modified crops, farming has in any way transformed in developed countries and is transforming in developing countries from being reliant on animal draught power to an industrial and commercial activity. The industrialisation of agriculture was well underway before genetically modified crops were developed. The development of the modern supermarket, with a focus on uniformity and consistency of product, suitability for storage and transport is both a more recent phenomenon. The next decade will see the shift from national to international supermarket chains and vertical integration of their activities – their marketing decisions will become tremendously important. Specification of residue levels etc at higher tolerances than Codex. The decision in early 1999 by some of Europe’s key supermarket chains: Sainsbury’s, Tesco, Marks and Spencer to ban genetically modified foods and potentially clothing produced from genetically modified cotton from their shelves may have greater implications for the markets for genetically modified crops in the immediate term than the outcomes of inter-government meetings and public education campaigns.

Technology is not inevitable. For example, after the use of nuclear power for electricity generation became feasible on a commercial scale in the 1960s, some countries such as UK have industries heavily based on this technology, while others such as Australia have decided not to develop nuclear power stations, and have maintained these views for several decades. A similar decision can be made by individual countries with genetically modified foods, not withstanding pressure from trade globalisation. Many of the benefits of modern plant biotechnology can be captured in conventional breeding programmes by use of molecular markers to track the gene s of interest in segregating populations.
Establishment of the World Trade Organization (WTO) was designed to assist with trade liberalization in agricultural products. Trade barriers based on food safety and quarantine concerns can be retained, but need scientific data to support the barriers. The Biosafety Protocol of the Convention for Biological Diversity will also relate to trade in genetically modified crops as it will attempt to develop regulatory harmonisation for biotechnology products. It is of particular interest to those developing countries that may lack national regulatory systems for genetically modified crops. Such harmonization will be difficult to achieve given the politicization of the debate around safety of genetically modified crops and differences in labelling requirements between countries. The role of the Codex Alimentarius Commission (set up in 1962 by FAO/WHO to establish international recommendations and standards on food safety) in setting negotiated international standards for labelling will almost certainly increase, especially since Codex methods are now recognised by the WTO. In June, 1999, US and Canada lodged a complaint to the WTO, claiming that the rapid rise in the number of countries requiring labelling of genetically modified foods is a technical barrier to trade, since they believe that exports of modified soybeans and maize to Europe is being harmed.

Belatedly, developing countries are becoming involved in the policy debate, contributing to an international forum on genetically modified agriculture convened by the US National Academy of Sciences and due to report by November 1999. A possible lesson for developing country governments and industry is that whatever their stance on genetically modified crops, good public communication is critical.

References


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