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GM Crops and Food Security

The rising global population requires agriculture to increase productivity at a time when land and water shortages and climate change are putting pressure on food production. This POSTnote examines the potential contribution that genetic modification of crops might bring to increasing food production in Europe, in a global context.

Overview

- The positive and negative environmental impacts of the use of GM crops vary on a case-by-case basis and are dependent on diverse factors.
- The EU has seldom approved the cultivation of GM crops. This is partly because member states differ in their political positions on GM.
- Development of some crop traits are more likely to succeed by advanced non-GM breeding techniques than by GM, but some traits can be achieved only by GM.
- Future GM technologies are being developed that will widen the possibilities for crop development, but will bring their own regulatory challenges.

Background

There is increasing anxiety about the global availability of food with nearly a billion people experiencing hunger, and many more suffering from malnutrition due to lack of micronutrients (POSTnote 367) [1]. Although trade and inequality are responsible for much of this, and food waste will need to be significantly reduced, agriculture will also need to produce more over the next 40 years. The recent Foresight report on "The Future of Food and Farming" suggested that by 2050, demand for food may rise by 70%[2]. This report highlighted the need for "sustainable intensification" – greater crop yields per input and per hectare, an approach recommended by the Royal Society's "Reaping the Benefits" report[3]. Sustainable intensification will require changes in agricultural systems, as well as development of crops that are better suited to lower inputs. Although the genetic yield potential of crop varieties has been increasing, the rate of commercial yield increases has been slowing or stagnating in recent years in many major crops in Europe[4] (Box 1). Both genetic modification and advanced conventional breeding have the potential to produce the 'step change' needed.

Box 1. Crop Improvement and Yield Gaps

The maximum potential yield of a particular crop variety is achieved when its specific growing conditions are ideal. The 'yield gap' represents the difference between potential and actual yields produced. Ideal growing conditions require optimal temperatures, light levels, water and nutrient availability for that variety, and a lack of competition from weeds or attack by pests and diseases. Yield potential is measured in standardised ideal-condition tests funded by a division of the Agriculture and Horticulture Development Board, and run by organisations such as the National Institute of Agricultural Botany (NIAB), to produce "Recommended Lists" of varieties for farmers. The aim for plant breeders has mainly been to raise the maximum potential yield and to improve crop quality. The aim for farmers is to produce a crop economically. Limitations on farmer investment in and use of water, labour, fertiliser, fuel, crop protection and technical advice, and market forces that do not always encourage the maximum yield, all contribute to the yield gap.

Genetic Modification

Genetic modification (GM) is a plant breeding technology that has been in use commercially for 16 years. GM crops are described by many different names – genetically modified organisms (GMOs), genetically engineered (GE), "transgenic" or "biotech" crops. GMO is the official term used in the EU. In general, these all refer to a plant carrying an inserted DNA sequence that does not occur naturally in its genome (a 'transgene') and which has not been created by conventional breeding.

In 2010, GM crops were commercially grown in 29 countries, including 8 in the EU, 5 in Asia and 3 in Africa, amounting to approximately 10% of global crop land[5]. The majority (>99% by area) consist of only four crops: maize, soybean, cotton and oilseed rape. Three main classes of trait are exploited:

- IR – Insect resistance (Box 2) – for maize and cotton
- HT – Herbicide tolerance (Box 3) – used for all four main crops, plus sugar beet and alfalfa
- VR – Virus resistance – used for papaya, squashes, peppers, and being developed for plums (as pictured).

HT, IR and VR are "agronomic" traits, intended to improve the management, quality and yields of the crops for the farmer. Other traits, such as "quality" traits aimed at the consumer or processor, include improved-starch potatoes.

Environmental Impacts

Measuring the environmental impacts of HT and IR crops is difficult, as potential impacts include effects on biodiversity, land use, water use, greenhouse gas emissions and inputs such as herbicides and pesticides, some of which may be indirect. These effects vary between different crop species and agricultural systems and may depend on how the GM crops are managed, so that studies vary in their methods and conclusions (see Box 3). The Advisory Committee for Releases into the Environment (ACRE), which is the statutory body for environmental risk assessment of GMOs in the UK, has produced a report on the comparative environmental assessment of all agricultural systems, including GMOs[6]. One concern about GM crops is the effect of gene flow. This is the spreading of transgenes to conventional crops or wild relatives by pollination. Its likelihood depends on the crop and its effect depends on the GM trait, factors included in the environmental risk assessments carried out for EU authorisation of GM crops.

Box 2. Insect Resistance (IR)

Most GM IR is conferred by "Bt" genes, which produce proteins that are toxic to only a few groups of insects, but non-toxic to other species including some pests. This specificity has made them very useful as insecticides, and Bt proteins can be used in conventional spray form, even in organic systems. The advantages of GM Bt plants include:

- reduction in insecticide spraying
- persistence of the insecticidal protein throughout the plant's life
- targeting of the insecticide solely to the plant to be protected.

Bt protects crops from pest damage, so the degree of yield increase of GM Bt vs. conventional crops depends both on the number of pests, which varies between years and regions, and on the ability to control pests by conventional means. Yield gains have been reported in several countries. GM Bt can also promote "quality" traits. Lower levels of insect damage to maize kernels reduce infection by mycotoxin-producing fungi, which can pose a significant health hazard. The environmental impacts of Bt have also generally been positive, mostly due to reductions in applications of broad-spectrum insecticides.

GM Crops and Resistance

There is a risk that target weeds or pests may become resistant to herbicides or pesticides. Herbicide resistant weeds have become a problem in parts of the Americas. Not all resistance has been associated with HT crops, but the large scale use of a single herbicide (glyphosate) has exacerbated the problem. Weed resistance has required the deployment of reactive measures, such as other herbicides, tillage and/or hand weeding. Proactive measures to prevent resistance from emerging are also increasingly being used. These include mixing herbicides, which reduces the risk of weeds becoming resistant to an individual herbicide.

Resistance to Bt in target insect pests has generally been slow to emerge, partly because of the use of refuges (areas of non-Bt crops) to reduce the risk of resistance developing. The application of other insecticides to control "'secondary pests", not targeted by Bt – in effect mixing the insecticides used, has also helped to limit resistance to Bt. Even so, some pests have become resistant, including the pink bollworm in India. Reduced spraying with broad spectrum insecticides has also led to increased infestation with secondary pests, especially in China. Farmer education is important to ensure methods to prevent and manage resistance are adopted.

Box 3. Herbicide Tolerance (HT)

Over 63% of GM crops grown globally have herbicide tolerant traits. Tolerance can sometimes also be developed through conventional breeding (e.g. clearfield canola). HT allows spraying of crops with broad-spectrum herbicide even after their emergence from the soil. The benefits to the farmer are improved, more flexible, weed control, resulting in fewer applications of herbicide. In practice, HT has allowed greater flexibility of farm management, promoting uptake of "Low/No Till" systems, which are agronomically and environmentally beneficial, and sometimes increasing the number of harvests[7]. These benefits, and the risk reduction HT provides, have contributed to the commercial success of GM HT crops, even though production cost savings may be cancelled out by the premium on GM seed[7]. However, the environmental effects vary. Decreased herbicide use and more flexible management are beneficial, but "Low/No Till" can be achieved without HT, and herbicide applications are not always reduced. In the UK, the "Farm Scale Evaluations" of GM HT crop management, GM sugar beet and oilseed rape decreased biodiversity, whereas with maize there was a slight positive effect. Weed control for GM HT beet and rape (but not GM HT maize), was more efficient than for non-GM varieties, but weeds support wildlife food chains, so their efficient removal reduced biodiversity. However, this study has been criticised for ignoring other potential environmental benefits of the crop.

Marker Assisted Selection

Non-GM crop breeding methods also have potential to increase yields. Selective breeding involves interbreeding varieties to mix their genes and then selecting progeny with desirable traits to breed from again. In the last two decades, advances in knowledge of plant genetics and decreasing costs of data have improved this selection process, and allowed the development of Marker Assisted Selection (MAS). MAS uses experimental information to link desirable traits to their underlying genes, allowing selection to be made more quickly and accurately. MAS has been extensively developed for several major crops, particularly maize and rice. MAS works most efficiently where there is a substantial genetic knowledge base, but in less-well studied species this may be unavailable and expensive to develop. GM and MAS can be used together, for example, GM may be used to insert a gene into one variety, then MAS may be used to breed the GM trait into different varieties (Box 4).

Box 4. GM vs MAS

GM and modern MAS both rely on scientific understanding of plants and have benefited from advances in biology, but differ in their capabilities:

- MAS is not a GM technique so products do not need GM regulation
- MAS is good for developing traits affected by many different genes ("complex traits") such as drought and salt tolerance
- current GM technology restricts the number of genes which can easily be engineered in, although new techniques may change this
- GM requires understanding of the action of the gene or DNA sequence, whereas that is not necessary for MAS.
- MAS can develop only traits present in closely-related species.
- GM allows the input of almost any gene, permitting introduction of traits not available within the species
- the characteristics of some crops or lack of research to provide information for MAS can make breeding difficult or extremely slow.

Regulation of GM crops in the EU

The regulation of commercial GM crops in the EU is carried out at the European Union level, as authorisation permits the free movement of the product throughout the zone. The legal framework covering GMOs is principally covered by Directive 2001/18/EC on the deliberate release of GMOs into the environment (for cultivation) and Regulation 1829/2003 on GM for food and feed (POSTnote 211). The EU has adopted the "Precautionary Principle" in its approach to GM crops. This advises caution with regard to the adoption of new technology, provided risk of inaction is not greater than risk of action. GMOs are required to undergo EU risk assessments for health and environmental safety. Based on these, the European Commission develops a proposal for granting or refusing an application, which is voted on by the Council of Ministers. The House of Lords EU Select Committee "Innovation in EU Agriculture'" report suggests that the EU's approach to GM is hampering its potential contribution as "global food security is likely to be threatened"[4]. Only one new GM crop has been licensed for cultivation in the last 13 years (the Amflora industrial starch potato in 2010) and only one other marketed crop has current approval (MON810 Bt maize).

No applications have been made for cultivation of GM crops in the UK. The approved crops are not grown here as the target pests for Bt maize are not a problem in the UK, and the Amflora potato is not relevant to UK industry. Traits and crops already exist that are suitable for UK agriculture (e.g. HT sugarbeet), and more are being developed. Potential products for the UK include disease resistant crops (see Box 5), herbicide resistant wheat (to deal with the pervasive weed blackgrass), and drought tolerant wheat. However, public concerns remain about the cultivation and consumption of GM crops, and particularly human health worries. The integration of public concerns with UK policy has been controversial. In 2010, the Food Standards Agency (FSA) GM dialogue project was discontinued[8]. In the recently released government policy on GM, it was stated that public views would be listened to, and planting of GM agreed only "if a robust risk assessment indicates that it is safe for people and the environment"[9]. It recognised that GM technology could deliver benefits to food security, provided it is used safely and responsibly.

Box 5. Blight Resistant Potatoes

GM potatoes resistant to late blight are being trialled in separate projects by the Sainsbury Laboratory in Norwich and by BASF Plant Science GmbH in Belgium. These potatoes are likely to be of commercial interest in the UK. Late blight is a fungus-like disease that can wipe out potato crops. It is currently controlled by up to 15 applications of fungicide a year. Blight resistant potatoes, for example the Sárpo variety, have been developed conventionally by interbreeding domestic potatoes with resistant wild relatives. This process has taken decades, as undesirable traits from the inedible wild potatoes have had to be bred out, and consumer preference means Sárpo potatoes are not yet suitable for supermarket selling. The GM potatoes also contain resistance genes from wild relatives that have been inserted straight into commercial varieties like Désirée. Resistance in both the conventionally-bred and GM varieties derives from wild relatives.

Provisions to accommodate EU member states that wish to ban GMO cultivation outright on non-safety grounds have been adopted by the European Parliament (COD(2010/0208)). However, as such, bans restrict the free movement of authorised products through the EU, doubts have been raised as to whether they are legally valid given the EU Treaty and World Trade Organisation principles.

Trade

The EU imports large quantities of GM. The EU and UK livestock industry is dependent on imported soy for feed, about 90% of which is from Brazil and Argentina[9], where its production was respectively 69% and 99% GM in 2009[7]. The trade in these commodity crops has been disrupted by presence of GM material not yet permitted in the EU, in part due to the EU's long approval process. Complete segregation of different varieties (non-GM or GM) for high-volume export is difficult, and the EU's zero tolerance approach to low level presence has meant that a few shipments with traces of EU-unapproved GM in them have been turned away, or destroyed if unloaded at an EU port. The effect of zero tolerance has been the subject of reports by Defra and the FSA[10], and the European Commission[11]. EU Regulation 619/2011 now sets a threshold for up to 0.1% of GM varieties which do not yet have EU approval in imports for animal feed, provided they are in the approval process and do not have any safety problems known to the European Food Safety Authority. However, incidents of low level presence and trade disruption are predicted to rise for both feed and food if the number of approved GM crops increases worldwide[12].

"Coexistence"

To allow "coexistence'" between GM and non-GM crops, segregation measures, such as separation distances, are needed to minimise gene flow. Coexistence also requires separation of material all along the production chain, including storage, processing and transport. Farm level issues include mixing through shared farm machinery and plants that grow in the years after the crop was first sown ("volunteers"). Coexistence measures are set by EU member states and should be proportionate (i.e. no more stringent than necessary). However, organic farmers are concerned that they may be disadvantaged as many certification schemes require *their* levels of GM to be undetectable.

GM and Intellectual Property

The use of patents on genes is controversial. There are concerns that in countries where GM technology is widespread in agriculture, seed companies may have reduced incentives to develop conventional varieties, as the market for these varieties is reduced, and they tend to have weaker intellectual property rights than the patents usually used with GM crops. In the USA, this is the case for soy, with conventional breeding now mainly left to universities and to small seed producers who focus on niche markets. The presence of patents may also limit public-sector research in some areas (Box 6).

Box 6. Intellectual Property (IP) and Public Projects

Although IP is a controversial area, GM seed producers have leased technology to public projects for free, such as with Syngenta and the Golden Rice project (POSTnote 367). Ways of managing IP are also being explored by not-for-profit and public organisations. The 2Blades Foundation seeks to improve crop disease resistance. IP developed by research funded by 2Blades is leased free to philanthropic concerns, while money from commercial applications is reinvested back into research. 2Blades also holds the licences to one of the new "'targeted mutagenesis'" technologies for producing GM crops (Box 7).

New GM Technologies and Regulation

Transgenic technologies in plants, in which DNA is inserted into genomes, are over 20 years old. Most commercial GM varieties produced, and in development, use these technologies, but methods have been developed that increase the flexibility and precision of GM (see Box 7). The effects of the genetic changes produced and the scientific and commercial status of these technologies is the subject of an EU report from its Joint Research Centre[13]. As some of the resulting plants will not be "transgenic" and possibly not detectable as being produced by GM techniques, the definitions that will apply to these plants (GMO or not) and their regulatory treatment are still under discussion in the EU.

Box 7. Developments in GM Technologies
Several new GM technologies have been developed;
- cisgenesis is a variant of transgenesis in which the gene being inserted into the plant originated from the same or closely related species. In the EU, it is classed and regulated as GM, but some scientists think it has less risk and needs less regulation, although this is disputed
- methods that avoid the use of antibiotic resistance genes are now possible. Previously, these genes were also inserted into transgenic plants as tools in the production process, but there have been fears that these genes could be transferred to disease-causing bacteria
- other developments completely change the method of generating GM plants. In current transgenics, a section of DNA is inserted at a random location in the genome. "Targeted mutagenesis" technologies, such as Zinc Finger Nucleases (ZFNs), can produce plants with precise changes to their DNA sequence but which are not transgenic (for example, which have DNA removed instead of inserted). Some of these changes would not be distinguishable from natural mutations if the method of production were unknown, and can be difficult to detect. The techniques also allow more flexibility and precision in the changes made, and can be combined with current transgenic technology. For example, ZFNs can be used to insert a transgene in a specific place, to reduce unexpected effects.

Near-market GM
In the short term, goals for crop improvement by GM include expanding traits for HT, IR, VR and resistance to other diseases in a wide variety of crops. Several of these are being developed by public institutions, although the cost of the regulatory requirements has limited the commercial development of GM crops by publicly-funded projects. GM development by companies has mainly focused on HT and IR traits and "stacking". This is the combination of different traits (conventional or GM) in one variety. Most GM plants are produced by insertion of one transgene at a time, but these can be combined using conventional breeding to produce plants stacked with several different IR proteins, or HT and IR. One variety has eight different transgenes. In the EU, each combination of stacked GM traits is regulated case-by-case, as for single traits, to assess possible interactions between them. Quality traits such as enhanced nutrient content (POSTnote 367) for consumers or oil compositions for industry are also being developed.

"Complex Traits"
Several traits are being developed to improve the ability of major agricultural crops to cope with reduced inputs and challenging conditions, particularly drought tolerance, salt tolerance and nutrient use efficiency (to improve uptake and use of nutrients such as nitrate and phosphate). These are "complex traits" involving several different plant processes and many genes. These traits are being developed by MAS and GM methods. Drought tolerant rice has been successfully developed by MAS, but breeding drought tolerant wheat has been more difficult. GM drought tolerant maize has not yet improved on the yields of non-GM varieties. Salt tolerance and nutrient use efficiency are less well developed. "Complex traits" also frequently involve trade-offs. For example, several drought tolerant wheat varieties have reduced yields when well watered. The environmental and social consequences of adopting these crops may be considerable, for example by allowing crop cultivation on previously unsuitable land.

Changing the Face of Agriculture
In the long term, ideal traits have been proposed that can be developed only by GM means. Staple crops that are perennial rather than annual, wheat and other cereals that can fix nitrogen in the same way as legumes, without the need for nitrogen fertiliser, and plants with more efficient photosynthesis (see Box 8) have all been envisaged. Development and commercialisation of these traits is decades away, but they are acting as drivers for the research community and may produce knowledge for smaller, short term developments for GM or conventional breeding. However, some NGOs are concerned that research projects for agricultural development based on technological approaches, that may fail to deliver, will be preferred by funding bodies over those based on agro-ecological methods, like Integrated Pest Management (POSTnote 336), which have previously received less funding.

Box 8. Enhanced Photosynthesis
Enhancing the photosynthetic capacity of plants, so that they can use more carbon dioxide and produce more biomass, is the focus of funding drives by both the Bill and Melinda Gates Foundation and a joint effort by the UK Biotechnology and Biological Sciences Research Council and the US National Science Foundation:
- the C4 Rice project is a global multi-institution consortium funded by the Gates Foundation. The project aims to test the feasibility of transferring a photosynthetic system called C4, which is more productive than normal ('C3') photosynthesis at higher temperatures, into rice. C4 researchers are using both GM and conventional techniques for different aspects of the research
- the BBSRC and NSF are funding four multi-institution photosynthesis projects. Three of these focus on photosynthetic systems from bacteria and algae. These are short term studies designed to explore possibilities and increase understanding, although there is more likelihood of producing intermediate systems with just a few transgenes for these simpler systems than for the C4 project.

Endnotes

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