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outlook

Global food security and the governance of modern biotechnologies

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Joyce Tait & Guy Barker

Food security has become an issue of serious concern because global food supplies are threatened by systemic collapse. Increasing demand for food caused by global population growth, changing lifestyles in developing countries, climate change and competition with biofuels are combining to create a 'perfect storm' (Godfray *et al*, 2010). Moreover, short-term weather pattern changes leading to floods and droughts and associated fires in key grain-producing areas of the world encourage speculation in agricultural commodities and cause wild price fluctuations. Drastic price hikes for staple foods during the past few years have triggered famine and revolts in developing countries, where people are hardest hit (Henn, 2011).

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Basic research into plant, animal and microbial physiology and molecular processes has yielded extensive knowledge about plants, their pathogens and symbiotic partners. Scientists and policy-makers are confident that the application of this knowledge could lead to new and more efficient approaches to crop production that will eventually improve food security. In this context, Europe has a particularly important role, as it contains highly fertile land and is agriculturally very productive.

However, European countries find it difficult to respond constructively to these challenges, given their divergent opinions on how to address food-security issues, particularly in terms of whether and how science and technology should be part of the solution. In addition, individuals and interest groups opposed to genetic modification and related technologies have influenced policy making in agriculture. Unfortunately, the European Union (EU) has yet to develop a coherent approach that allows European citizens to reap the benefits of scientific progress and prevents special interests from dominating decision-making processes. European regulatory systems—instead of scientific progress—will therefore determine whether technology-based solutions are part of the future of agriculture within Europe, and in many other countries. This article explores the link between regulation and innovation in the context of food security in Europe, and considers the impact of European policy on the ability of other countries to respond to food-security challenges.

Foresight and horizon-scanning are important tools for the development of government policies and planning. They help to determine both the level of investment in scientific research and the policies that facilitate the application of such knowledge. Unfortunately, for more than a decade the prevailing policies in Europe have been either negative or neutral towards innovation for agricultural production. This has led to a lack of new genetically modified (GM) crop varieties for European agriculture and created an environment that is unreceptive to their application.

Two recent Foresight reports from France (INRA and CIRAD, 2009) and the

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UK (Government Office for Science, 2011) have discussed the looming food security crisis. Their conclusions reflect the differences in national perceptions, in particular the expected role of biotechnology in addressing the problems. The French Agrimonde report considered two scenarios. Agrimonde GO, describes a global free-trade economy that allows the rapid diffusion of new technologies and an expanded area of biomass production for biofuels. Mechanized, industrial farming is the norm—supported by GM crops—with plant and animal production largely controlled by multi-national companies. By contrast, Agrimonde 1 describes a suite of policy options at national and international levels—including strong regional planning policies to limit the 'artificialization of the land'—supported by 'massive aid',

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and regulated by a new United Nations organization to avoid distortions in competition and food-price volatility. Innovation in this case is seen as a process of 'ecological intensification': an alternative to modern agricultural systems that steers ecological processes instead of controlling them. The authors of the report preferred the Agrimonde 1 scenario, perhaps influenced by public support in France for small, family farms.

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Although efforts such as ecological intensification are laudable, the required policy approaches have so far eluded the efforts of several national and international agencies and non-governmental organizations (NGOs). It would therefore be unwise to rely entirely on something such as the Agrimonde 1 scenario to guarantee food security. Similarly, the Agrimonde GO scenario is unlikely to exist in the extreme form presented in this report. The rapid diffusion of new technologies, along with mechanized farming and GM crops—whether or not these are controlled by multinational companies—will probably be needed to meet future challenges in agriculture. However, there is no reason that such a scenario could not include measures to foster biodiversity on land areas that are not used to grow crops (Tait, 2001a). Indeed, more productive GM crops could actually lead to better coexistence between intensive agriculture and biodiversity (Dewar *et al*, 2003; National Research Council, 2010) and future biotechnologies could be more effective in this respect if policy was used to drive innovation in that direction. Ultimately, the French approach—setting up two extreme Agrimonde scenarios with the aim of forcing choices—rarely provides a viable basis for decision making, although it can influence attitudes.

The UK Foresight report 'The Future of Food and Farming' (Government Office for Science, 2011) analyses the predicted pressures on the global food system up to 2050. There are five key challenges addressed in the report: balancing future supply and demand sustainably; addressing the threat of future volatility in the food system; ending hunger; meeting the challenges of a low emissions world; and maintaining biodiversity and ecosystems while feeding the world. The report identifies policy decisions to ensure that the growing world population can be fed sustainably and equitably, and recognizes the failings in current food production systems. It identifies priorities for action including investment in new technologies, such as genetic modification, cloned animals and nanotechnology, which are regarded as essential and should not be excluded on moral or ethical grounds. The need to respect the views of people with contrary opinions is recognized, but so is the need to keep policy options open and to make decisions about the acceptability of new technologies in the context of other risks and the costs of not using these technologies.

The UK report is more pragmatic in tone than Agrimonde, and more accepting of technological solutions. Among other things, it proposes using technology to improve global food security in ways that will not necessarily lead to environmental decline. Indeed, technological approaches could lead to better environmental performance than conventional farming systems, without making unrealistic demands on national and international governments.

The EU has also recognized the problem of food security. It announced an initiative on Agriculture, Food Security and Climate Change, to be jointly led by the National Institute for Agricultural Research (INRA) and the UK Biotechnology and Biological Sciences Research Council (BBSRC; INRA, 2010). It is one of several Joint Programming Initiatives (JPIs) that pool national research efforts to make better use of financial resources; in this case, more than €1 billion annually. However, given the differences in the national cultures and agendas of its leading partners and the diversity of views among the other partners, this JPI might find it difficult to achieve a single voice and deliver the expected improvement in using resources more efficiency.

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If we were to adopt a more technology-oriented approach to guarantee food security, it would need to include targeted research on modern crop and animal science, agro-ecology, agricultural engineering and aquaculture management (Government Office for Science, 2011). In addition, the UK Foresight Report refers to long-term advances, such as the development of perennial grain crops, the introduction of nitrogen fixation into non-legume crops and the re-engineering of photosynthetic pathways of different plants. Consequently, investing in basic science remains an important priority, as does ensuring that the regulatory environment does not unnecessarily constrain the translation of knowledge into new products and processes.

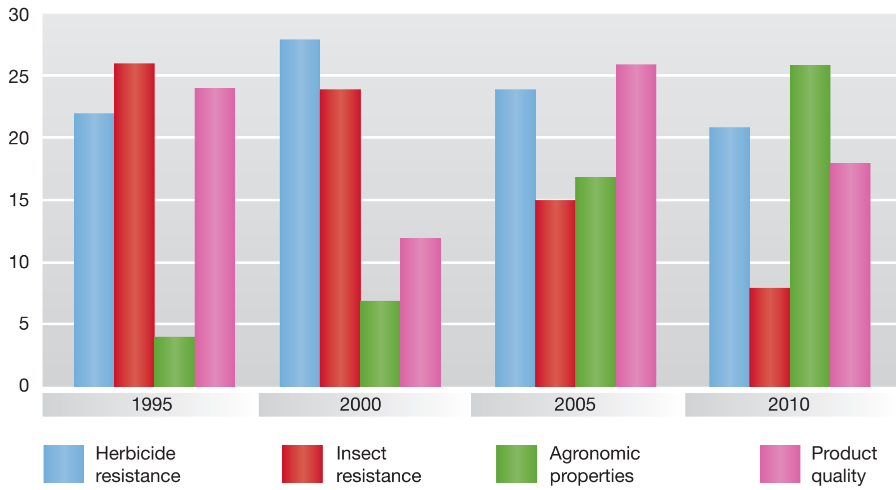

Fig 1 | Genetically modified traits in crops undergoing trials in the USA (1995–2010)

Available technologies, particularly GM, are making a large contribution to global food production. Outside the EU, the cultivation of transgenic crops is expanding rapidly. The increase from 1.7 million hectares in 1996 to 148 million in 2010 makes biotech crops the fastest-adopted crop technology in the history of modern agriculture, now covering 10% of land that is used for crops on Earth (James, 2010). Depending on the crop and the farming system, GM crops are already contributing to increased yields, greater ease and predictability of crop management, a reduction in pesticide use and fewer post-harvest crop losses (National Research Council, 2010).

Nevertheless, more research is needed to generate a broader variety of crops to address future changes in farming systems (Fig 1). Current developments promise many improvements related to food security, including yield increases, better nitrogen-uptake efficiency, improved heat, salt and drought tolerance, improved root growth, cold germination and timing of flowering. More knowledge and better genetic modifications can benefit agriculture, as exemplified by Jiao *et al* (2010) who have developed a new rice variety by mutating a gene that affects plant architecture, increasing yield by 10%. Another example is submergence-resistant rice, which could benefit many developing countries.

In addition to GM crops that contain transgenic modification—that is, genes from different species—technological and scientific advances are improving the efficiency of traditional plant breeding (Table 1). Ideally, such techniques would be used with GM and other approaches to provide a suite of techniques from which researchers can choose the one that is best-suited to their needs. However, scientists in the EU might find themselves in a situation in which they can only use non-GM techniques, because they are more likely to be funded or because the product is less likely to be delayed in the regulatory system, or rejected altogether.

The regulation of GM crops and related biotechnologies has led the way for a shift in policy style in Europe since the 1980s. There has been a move away from top-down government towards bottom-up governance, with the underlying assumption that this will lead to more democratic decision-making. This approach is characterized by the involvement of non-government actors, an increasingly complex set of state–society relationships, and a blurring of the boundaries between the public and private sectors. The role of the state changes from being the main provider of policy to facilitating interaction between interested parties (Lyall & Tait, 2005).

Along with the rise of governance as a basis for policy decisions, the 1980s saw a change in the regulation of new technologies for agriculture and food production in the EU. Under the previous government approach, regulation focused on the final product and its potential effects on human or environmental health. Starting in the mid-1980s, the precautionary

Table 1 | New plant-breeding techniques

Technique	Function	GM-free end product?
Genetic manipulation as a tool to facilitate breeding		
Virus-induced gene silencing	Transient silencing of specific genes for functional analysis.	Yes
Agro-infiltration	Uses *Agrobacterium* to achieve temporary, local expression of genes that are foreign to the species, for example to test the ability of a plant to resist pathogen attack. *Agrobacterium*-free cuttings or seeds are used for further development.	Yes
Reverse breeding	To produce improved F1-hybrid varieties that are free from introduced genes.	Yes
Accelerated breeding	Genetic modification is used to speed up breeding by inducing early flowering.	Yes
Grafting of non-GM material to GM material		
Chimeric plants	For example, non-GM plant grafted onto a GM rootstock to improve cultivation characteristics. The harvested part of the plant will not contain foreign DNA, although RNA transcripts and metabolites can pass into the harvestable parts of the plant.	Yes
Genetic modification using material from the same species or a sexually compatible species		
Cis-genesis	Uses DNA from the same species or a cross-compatible species. The regulation of gene expression is unaltered from the native state. The product could be generated by conventional breeding.	No
Intra-genesis	Similar to cis-genesis, but incorporating new combinations of regulatory and coding sequences, normally for silencing genes.	No
Genetic manipulation as a tool for inducing specific mutations		
Oligonucleotide-mediated mutation	Causes site-directed mutations within genes. Used to knock out or adapt gene function. Plants are similar to those obtained through traditional mutagenesis-based breeding.	Yes
Zinc-finger nuclease	Zinc fingers are attached to a protein that cuts the DNA between the recognition sites matched by the fingers. The cell repairs the DNA and thereby knocks out the gene. If a new gene is inserted at the same time as the zinc fingers, the new gene can be inserted at the break site. Dow Agrosciences has licensed this technology for creating new crop plants.	Yes

Based on Schaart & Visser (2009). GM, genetically modified.

principle—that had originated in German planning law (von Moltke, 1987)—was increasingly advocated as the basis for the regulation of new technologies. An influential report from the UK Royal Commission on Environmental Pollution (RCEP, 1989) supported the precautionary principle as the basis of the regulation of GM crops, in line with a general trend in GM crop regulation in Europe (Tait & Levidow, 1992).

As the European regulatory system for crop biotechnology has been changing, new requirements have been added and their applications have been extended to new areas. For example, even if a new crop variety has no GM traits, the regulatory system for GM crops—which costs, on average, €6.8 million per variety—is still applied if the development of the variety involves a GM step (Table 1; Schaart & Visser, 2009). These costs restrict the development of new crop varieties using GM techniques; a situation that would be justified only if there was evidence of a proportionate degree of risk. Moreover, case-by-case regulatory scrutiny has been interpreted to the point that every variety of a crop into which a similar GM event is introduced is subject to the full regulatory regime (EFSA, 2010). Separation distances, which aim to avoid contamination of organic and conventional crops with GM produce, are governed by a standard that bears no relation to any risk to people or the environment, and which was strongly influenced by the organic farming lobby.

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The interaction between the governance-based approach and the precautionary principle has exposed decision-making on the regulation of GM crops to influences from politically motivated parties more than ever before. The result has been greater restriction of plant biotechnology in Europe than in other parts of the world, despite a lack of evidence for any direct risks from the wide-scale adoption of GM crop technology. Indirect negative effects—that will arise from any intervention in complex agricultural systems—are usually outweighed by the benefits (Park *et al*, 2011; Smythe *et al*, 2011).

The cost and complexity of the EU regulatory system for GM crops, along with the lack of evidence of harm to people or the environment, is generating pressure to make regulatory systems more risk-based and to take potential benefits into account (Kuiper & Davies, 2010; Schaart & Visser, 2009). However, in Europe and other parts of the world, lobbyists and individuals with an anti-GM agenda retain considerable influence with policy makers.

Public engagement is seen as an essential component of the governance approach. From surveys to focus groups to citizen juries, GM crops have probably been engaged with more than any other technology, but this has not helped to build societal consensus in Europe.

Notwithstanding, the proposed solution to the on-going impasse seems to be even more engagement. For example, in 2009, the UK Food Standards Agency (FSA) planned to undertake a public dialogue with the aim of helping to "…ensure that future government and non-governmental policy towards the availability and production of food which involves the use of genetic modification is informed by a thorough understanding of the public's principal concerns and priorities in respect of such food." The FSA justified their initiative with, among other things, the possible crisis in global food security (FSA, 2010).

The initiative was abandoned in its early stages after two members of the steering committee resigned—one is a member of an anti-GM NGO; the other is an academic.

Given the tone of the letters (http://www.sciencewise-erc.org.uk/cms/food-the-use-of-genetic-modification-a-public-dialogue/), these resignations could be interpretted as politically motivated. If the dialogue had gone ahead there would probably have been on-going debate and disagreements in the steering committee over the content of the background materials used to inform the public dialogue, particularly the extent to which it was supported by scientific evidence (Chataway *et al*, 2008).

> **The main concern of the EU should be to enable science and technology to contribute to food security**

The strategy adopted in this case by those opposed to GM—invoking democracy and public dialogue, as well as working behind the scenes to influence the dialogue and its treatment in the media—has been characteristic of debates about GM technology in Europe for the past 10–15 years. Stilgoe (2006) has noted that the role of NGOs in stakeholder engagement is often to shape the public debate according to their interests and values. This strategy will continue to be effective for as long as there is no demand—particularly in the media—for more-balanced treatment of the two sides of the argument (Tait, 2009).

Pielke (2007) has described four potential roles for scientists engaging in policy and politics: the pure scientist, the science arbiter, the issue advocate and the honest broker. Two of these roles are relevant to discussions about GM crops in general: the issue advocate and the honest broker. The issue advocate focuses on the implications of research for a particular political agenda, is aligned with a particular set of interests and seeks to participate in the decision-making process to further these interests; the honest broker clarifies possible outcomes and seeks to expand the choices available to decision makers, but refrains from advocating any particular course of action. The issue advocate category describes the role of NGOs and other advocacy groups, for example industry lobbies, and the honest broker refers to the role expected of scientists who advise governments.

Pielke also points to the existence of 'stealth issue-advocacy', which allows an adviser to claim to be "…above the fray, invoking the historical authority of science while working to restrict the scope of choice". The European history of policymaking and engagement with developments in agricultural biotechnology has been characterized by effective issue advocacy from NGOs and less-effective issue advocacy from industry, along with a key contribution from stealth issue-advocacy against GM crops from some members of the academic community. The fact that these strategies have been able to frustrate the recent FSA public dialogue is not reassuring for the future of GM and other advanced biotechnologies in contributing to food security in the UK and the EU.

Another example of the power of advocacy to influence European decision-making on GM crops is the French Agrimonde report. Immediately after its publication, it seemed likely that France would adopt a more liberal approach to GM crops. When asked about the role of biotechnology in food production, Marion Guillou, Chief Executive of INRA in France, cautiously referred to the need for new genetically selected varieties, either produced by GM or traditional breeding techniques. She supported case-by-case scrutiny of GMOs, acknowledging that for some GMOs assessments are undisputedly positive, particularly modifications that provide insect resistance and allow a reduction in pesticide use (Anon, 2010). However, INRA has since announced that it does not intend to make GM plant varieties available for sale in France. Guillou said, "We have no research on GMO innovation anymore, none. […] Since European society does not want to buy GMOs, we had better focus on other technology" (http://www.forexyard.com/en/news/French-researcher-halts-development-of-GMO-crops-2010-10-29T080856Z-INTERVIEW).

Thus, governance-based policies, linked to the precautionary approach, have led us to a less democratic and less evidence-based system, in which regulation and restriction of specific areas of scientific activity are seen as a valid response to societal pressures, instead of a means of dealing with demonstrated risks.

The main concern of the EU should be to enable science and technology to contribute to food security. The relevant technologies must be effective and safe, and their societal acceptability should be determined by a process that is as democratic as possible to balance the interests and values of various stakeholders, as proposed in the UK Foresight paper (Government Office for Science, 2011). The dilemma in the EU is the ideological basis for most of the opposition to GM and related technologies (Tait, 2001b), which makes it hard-to-impossible to resolve conflicts and might even exacerbate them (Sunstein, 2009). The recent FSA dialogue on GM foods supports this conclusion.

It is difficult to collect evidence of benefits or risks, given the routine destruction of GM-crop field trials by NGOs opposed to the use of the technology (Tait, 2009). It is difficult to develop new GM products that could be beneficial for the environment or contribute to food security when there is a lack of funding for basic research and development to produce such products. It is impossible for small companies to develop GM crops, as is generally advocated by the public, when the cost of regulatory requirements is so high that only large, multinational companies can afford it.

> **If Europe is to meet its own food security needs and contribute to the food requirements of the rest of the world, policy and regulatory changes will be necessary**

It is ironic that European citizens are unhappy with the dominance of food production by large, multinational companies and their focus on global commodity crops instead of the needs of the developing world. This is the inevitable outcome of a regulatory system that has been applied to plant biotechnologies in response to pressure from advocacy groups (Tait, 2007). The most efficient way to overcome the dominance of multinational companies in food-production systems is a regulatory system that is cheaper and faster, but which assures safety and efficacy. This would enable smaller companies to develop GM crops for niche markets, including those in the developing world.

However, given Europe's commitment to a governance-based approach, along with the existence of strong issue and stealth issue-advocacy against GM crops, not to mention the implacable opposition by some NGOs, it is difficult to envisage how regulatory reform could be discussed constructively, let alone implemented.

We could take a step back to use more government-based approaches that require the separation of factual evidence from the political process of dealing with conflicting interests and values. Under the government approach, advisers are expected to take a role equivalent to Pielke's honest broker, whereas the governance approach has encouraged issue advocacy. The governance experiment of the past 15 years—involving a more bottom-up, stakeholder-led approach to risk management (Lyall & Tait, 2005), as applied to agricultural biotechnology—has not delivered greater consensus in decision-making or more innovative products of benefit to society; instead, it might have prevented these outcomes. The implications of adopting this attitude and the resulting prohibitive regulatory regime have had effects beyond Europe. Many other countries are also resistant to the use of GM crops, because governments fear that they would not be able to export their products to the EU. Unfortunately, this affects several developing countries that already face food shortages, and whose farmers might benefit from growing GM crops.

Europe once had a great deal to offer in terms of an environmentally oriented approach to agricultural technology, but policy and stakeholder interactions related to GM crops and biotechnologies over the past 10–15 years have so far prevented these benefits from being realized. If Europe is to meet its own food security needs and contribute to the food requirements of the rest of the world, policy and regulatory changes will be necessary. However, we do not yet have a mechanism for stakeholder engagement that could lead to more democratic outcomes in the context of polarized and ideologically motivated opinions (Sunstein, 2009). We will need clearer strategic thinking on how to implement a governance approach under these circumstances for the investments we make in scientific research to contribute to food security.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Joyce Tait is at the ESRC Innogen Centre, University of Edinburgh, Edinburgh, UK. Guy Barker is Director of the Genomics Resource Centre at the University of Warwick, Warwick, UK.
E-mail: joyce.tait@ed.ac.uk

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