

science & society

Stop worrying; start growing

Risk research on GM crops is a dead parrot: it is time to start reaping the benefits of GM

Torbjörn Fagerström, Christina Dixelius, Ulf Magnusson & Jens F. Sundström

Ever since the Asilomar Conference on 'Recombinant DNA' in February 1975, regulatory policies relating to recombinant DNA technology have focused on the idea that this technology implies threats to human health and the environment [1]. As a consequence, the explicit goal of these policies is to protect society and nature from an assumed hazard, or, if protection is not possible, at least to delay the implementation of the technology until scientific evidence shows it to be harmless. These policies were widely accepted at the time, as public concerns were, and still are, important. As time has gone by, the evidence for negative impacts of genetically modified (GM) crops has become weaker. However, the regulatory policies within the EU are still rigid enough to prevent most GM crops from leaving the confined laboratory setting; should some candidate occasionally overcome the hurdles posed by these policies, the precautionary principle is invoked in order to ensure further delaying in its use in the field. The reason for this over-cautious approach is widespread public resistance to GM crops, caused and amplified by interested groups that are opposed to the technology and invest heavily into lobbying against it.

As time has gone by, the evidence for negative impacts of genetically modified (GM) crops has become weaker

Against this background of political resistance, it is no surprise that the risks, costs and potential disadvantages of not growing GM crops have received little or no attention. These disadvantages become increasingly relevant as the scientific arguments for the prevailing resistance to GM

crops become weaker. Twenty-five years of risk research on GM crops have established beyond reasonable doubt that biotechnology is not *per se* riskier than conventional plant breeding technologies [2]. The whole seemingly endless discussion about purported risks of GM crops is akin to the famous Monty Python sketch in which John Cleese is trying to return a dead parrot to shopkeeper Michael Palin, who, despite the evidence, insists that the bird is well, alive and "pining for the fjords". Instead, we need to highlight the opportunities missed by not accepting GM crops. These include lost revenues for farmers, breeding companies and consumers, brain drain and lost technology innovations, reduced agricultural productivity and sustainability, foregone health benefits, especially reducing malnutrition, and many more realized or expected virtues of GM crops [3].

Risk assessment and risk analysis of genetically modified organisms (GMOs) is governed by internationally accepted guidelines, developed by the Codex Alimentarius Commission (www.fao.org). One leading principle is the concept of substantial equivalence, which stipulates that any new GM variety should be assessed for its safety by comparing it with an equivalent, conventionally bred variety that has an established history of safe use [4]. Despite the fact that the Codex Alimentarius guidelines are globally endorsed, the authorization procedure for GMOs differs substantially between national jurisdictions. Europe stands out as being considerably more restrictive than countries in North and South America and parts of Asia, for example. Within the European Union (EU), a common regulatory legal framework such as Regulation (EC) No. 1829/2003, governs GM crops

intended for human food and animal feed. Any party seeking approval for an edible GM crop must provide extensive scientific documentation that demonstrates that the food or feed derived thereof has no adverse effects on human and animal health or the environment, does not mislead the consumer, or does not differ from the food it is intended to replace to such an extent that its normal consumption would be nutritionally disadvantageous for the consumer.

In a report from 2010, the EC [...] concluded that biotechnology is not *per se* riskier than conventional plant breeding technologies

The risk assessment is conducted and compiled by the applicant, and is evaluated by the GMO Panel of the European Food Safety Authority (EFSA). The opinion of the panel should form the scientific basis when member states provide other legitimate arguments and cast their votes in the Standing Committee for Food and Animal Health of the European Commission. Thus, the decision to approve a particular GMO should be on the basis of scientific grounds. By the same logic, one might take for granted that only GMOs that have been shown to have adverse effects on animal or human health or the environment will not receive approval. In practice, however, the decision whether or not to approve a particular GMO is not solely a scientific issue. Several member states vote, in principle, against approval, irrespective of the scientific opinion delivered by the EFSA [5]. In recognition of this dead-lock, the European Commission (EC) has suggested that individual member states should have

the right to restrict cultivation of a given GM crop even if there are no scientifically established risks, that is, to adopt restrictions on the basis of socio-economical or ethical grounds [6].

... it is time to look at the other side of the equation and gauge the possible benefits of adopting and growing GM crops

In addition to the scientific documentation provided by the applicants who seek approval of a GM crop, public research has investigated the risks of GMOs during the past 15 years. The Directorate-General Research under the EC has spent €200 million during the past decade on such research, and several member states have initiated national research programmes specifically targeting the potential impact of the very same crops and traits that are in the European approval system [2]. A collaborative working group under the Standing Committee on Agricultural Research (SCAR) has estimated that the funds allocated to national risk research on GMOs in 13 European countries amount to at least €120 million during the past eight years (http://bmj.gv.at/home/Schwerpunkte/Gentechnik/Fachinformation_Allgemeines/SCAR_Collaborative_Working_Group_Risk_Research_on_GMOs).

In a report from 2010, the EC summarized the results of 130 research projects involving more than 500 independent research groups and concluded that biotechnology is not *per se* riskier than conventional plant breeding technologies [2]. Further support for this position comes from the UK Farm-Scale Evaluation (FSE), which studied the potential impact of herbicide-tolerant crops on farmland biodiversity [7]. One insight from the study is that overall changes in agricultural management determine the impact of a crop on biodiversity, rather than the technology or breeding behind the crop itself [8].

Between 2008 and 2009, the EFSA GMO panel evaluated a renewal to permit the continued import, processing and cultivation of maize variety MON810 for food and feed. MON810 expresses the Cry1Ab protein from the soil-borne bacterium *Bacillus thuringiensis* (Bt), which confers resistance to the European corn borer, and is one of two GM crops approved for cultivation in Europe; it was first approved in 1998. As a

basis for its 2009 opinion, the EFSA GMO Panel summarized 48 peer-reviewed papers on the potential risks of MON810 on animal and human health and the environment, in addition to the documentation provided by the company [9]. It found no adverse effects and concluded that MON810 is comparable with its conventionally bred parental lines. The only difference reported was that MON810 has an increased variability in lignin content, in some studies it has been found to be higher and in some studies lower. Similarly, a review by Icoz & Stotzky [10] of studies on the effects of insect-resistant Bt crops on soil ecosystems found no notable detrimental effects on microbes and other organisms in below-ground soil ecosystems. Accordingly, the authors concluded that "...available funding would be better spent on studies of the potential risks associated with the release of transgenic plants genetically engineered to express pharmaceutical and industrial products that, in contrast to Cry proteins, are targeted primarily to human beings and other higher eukaryotic organisms."

If, as 15 years of intense research and risk assessment have shown, GM crops do not pose greater risks for human health or the environment than conventionally bred varieties, it is time to look at the other side of the equation and gauge the possible benefits of adopting and growing GM crops. To that end, Fagerström & Wibe [11] analysed the potential economic consequences for Sweden of farmers not growing GM crops—herbicide-tolerant sugar beet and canola, and late blight-resistant potato—and then extended the analysis to all of the EU. They considered two rough categories of impact: effects that could be evaluated by studying market prices that show impacts for producers on workforce and capital, and demand for fertilizers, pesticides and fuel, and factors related to the cost of keeping GM crops separated from conventionally or organically grown crops during cultivation, harvest, transport, storage and processing. The latter cost arises from the European attitude of regarding GM crops and products as contaminants—as if we were dealing with toxic substances.

In 2008, Sweden produced almost 2 million tons of sugar beet grown on approximately 37,000 hectares and with a production value of €70 million. The authors calculated that a shift to herbicide-tolerant sugar beet could have led to a 5–10% increase in yield. Expenditure

on seeds would increase from €180 to €210 per hectare, but the cost of herbicides would decrease from €180 to €55. Taken together, the cost of input goods would decrease by 27%.

Analysis of the sugar beet shows that the economic value to producers and, by extension, to society is strategically dependent on two factors: the cost of keeping GM sugar separate from conventional sugar, and the public acceptance of GM sugar. The crucial limit was found to be a separation cost of 25% of the price; at this limit, the economic value to society vanishes even if all consumers buy GM products—if public acceptance is 100%. In a realistic scenario the separation cost is ~10% of the price and the public acceptance is ~25% of the consumers. Thus, the economic benefit would be €1.3 million, or ~2% of the total value of sugar beet production. If GM crops enjoyed full public acceptance, and if there were accordingly no costs of separation, the economic gain to society would amount to €10 million; about 14% of the total value of sugar beet production. Approximately 3,000 hectares of arable land—8% of the acreage of sugar beet—would be available for other uses.

... not adopting modern breeding tools—including biotechnology—will probably hamper the European agricultural systems facing a warmer and more variable climate

Similar values apply for potato and canola, so introducing these three GM crops in Sweden would yield an economic value of €30 million annually. In addition, producers would regain 10,000 hectares (ha) of arable land; using official statistics on leasing costs for arable land in Sweden, this has an annual value of approximately €2 million. This adds up to a combined annual value to society of €32 million. The accumulated value of this annual revenue over many years—the so-called capitalized value—is €1–€1.6 billion at an interest rate of 2–3%. The annual gain amounts to approximately 14, 11 and 5% of the production value for sugar beet, canola and potato, respectively. EU-wide, a shift to these three GM crops would yield a gain of ~€2 billion annually, and would save ~645,000 ha, which corresponds to a capitalized value in the range of €80–€120 billion.



These calculations presuppose full public acceptance of GM crops; that is, a world in which consumers perceive GM crops as equal to or better than non-GM varieties. In addition, the results rest on the assumption that the benefits to the environment such as decreased use of pesticides can be measured by the cost of the pesticides. Presumably, this is an underestimate of the environmental benefits, and the societal value is therefore probably greater than the figures presented above.

Other studies address the problem of missed economic benefits, often using economic models similar to those used by Fagerström & Wibe [11]. Generally, they confirm the results discussed above: the magnitudes of the unrealized benefits are similar. Matin Qaim, an agricultural economist at Göttingen University, Germany, for example, presented figures for Bt cotton adoption that would entail global welfare gains in the range of €0.5–€1.0 billion per year [12]. The biggest impact occurs in China, but India, where the relevant technology was more recently commercialized, has been catching up rapidly. It is estimated

that the widespread adoption of Bt cotton in India and other countries of South Asia will result in further regional welfare gains on the order of €1 billion per year.

The benefits of adopting GM oilseeds and maize are amplified by the larger international markets on which they are traded. While the annual global welfare gains at the present moderate level of adoption are estimated at €3.5 billion [13], this figure could reach approximately €7.5 billion with widespread international adoption of herbicide-tolerance and insect-resistant crops [12]. However, it is also noted that a ban on production and imports by the EU could reduce these global gains by two-thirds owing to unrealized benefits for domestic consumers and the far-reaching influence of EU policies on international trade flows and production decisions in other regions.

Large global welfare gains are projected for GM rice as well. Assuming that there is moderate adoption of GM rice in rice-producing regions, the combined global welfare gains are estimated to be in the region of €5 billion per year for Bt-carrying, herbicide-resistant and drought-tolerant

rice varieties, with India and China gaining the most. Projected welfare gains in China alone could reach more than €3 billion when first-generation GM rice technologies are widely adopted. Both studies [11,12] highlight that available analyses probably provide lower estimates of the global welfare effects of GM crops, because other environmental and health benefits have not been properly quantified.

Agriculture is blamed frequently for biodiversity loss. Several recent studies, however, demonstrate that the design of the agricultural landscape, with refuges for non-crop species, intercropping and crop rotation, can counterbalance the effects of an intensified agriculture system [14]. Hence, one of the most important consequences of better yields from herbicide and pest-resistant GM crops in Europe would be that the surplus land could be used for refuges to promote biodiversity in the farming landscape and save natural forests from deforestation or wetlands from being drained to make way for farmland. However, regulations regarding cultivation

distances, as well as other measures to keep GM crops separate from conventionally bred varieties, lock GM crops into large-scale agricultural practices and, in effect, prevent intercropping. Thus, the principle of non-coexistence limits the scope for farmers to take full advantage of the benefits of present and future GM crops to further reduce the need for pesticides and increase the productivity of farmland. This line of reasoning is supported by a recent study showing that the willingness of farmers to adopt GM crops is substantially hampered by the costs and uncertainties associated with coexistence regulations, despite lower costs for chemicals [15].

Historically, cereal crop varieties have been replaced by new varieties on average every 5–10 years [16]. The reasons for this turnover vary, but one underlying drive for crop replacement is the rapid loss of resistance traits. In order to maintain yield levels, farmers must either increase their use of chemicals to kill pests, or change to a new crop variety; hence the continuous breeding for resistance traits. Imminent climate changes will put further constraints on agricultural production, including an increasing need for faster and more efficient plant breeding to adapt crops to more variable local conditions [17]. If breeders fail in this regard, agro-chemical use will increase and Europe will become more dependent on imports. In Europe, the spatial variation in rainfall is expected to increase: Northern Europe can expect a more humid climate, which will constrain crop production owing to the increased severity of biotic stresses such as insect pests, fungal pathogens and the invasion of alien, noxious species, whereas crop production in southern Europe will have to be adapted to drier conditions [18,19]. Thus, not adopting modern breeding tools—including biotechnology—will probably hamper the European agricultural systems facing a warmer and more variable climate [20].

Legislation that determines what constitutes a GMO was ratified in 2001. In a legal sense, a GMO is defined as an organism in which the genetic material has been altered in a way that does not occur naturally by mating or natural recombination, and refers to both plants and animals, except humans. In practice, a GMO is defined by an addendum to the Directive 2001/18EC, which lists the techniques that give rise to a GMO. Since the Directive 2001/18EC was ratified,

ten years have passed, and technology has progressed further. Many of the techniques listed in the addendum have been improved or are obsolete. A recent report to the EC by the Joint Research Centre [21] describes new methods, their possible applications for plant breeding and potential implications for agriculture. One common aspect of the new techniques is that many involve the use of recombinant DNA or RNA molecules in one phase of the breeding process; however, these recombinant molecules are not present in the final product and are commonly not transmitted to the next generation.

... the burden of EU legislation for GM technologies is completely out of proportion compared with other science-based endeavours

Interestingly, European scientists at public and private institutions are at the forefront of technological development concerning new breeding. In this respect the situation is similar to the history of plant transformation technologies first developed at European universities [22], but now mainly used outside Europe [23]. By way of illustration, BASF, the company that developed the Amflora potato, announced recently that it is halting research on GM crops in Europe. Ultimately, the development and success of scientific know-how and new technology in Europe, as well as the adoption of new techniques and crops, will depend on the decisions made by European legislators who are discussing GM technologies and their ratification.

As a comparison, other genetically engineered products, such as biopharmaceuticals, are approved for humans and food-producing animals after ordinary science-based safety assessments [23], without the ideological stigmatization and biased decision-making processes seen for GM crops.

Our review of the state-of-affairs of GM crops in Europe raises several fundamental issues. First, the burden of EU legislation for GM technologies is completely out of proportion compared with other science-based endeavours. This is manifested by the substantially longer time required for a GM product to reach approval within the European legal framework (45 months), compared with GMO-exporting countries such as the

USA, Canada or Brazil (27 months) [24]. In addition, these European approval times are only valid for importing commodities; approvals for cultivation in Europe take substantially longer. It took 14 years for the Amflora potato, for example, which is only the second GM crop to be approved in Europe. Not only are rules more restrictive in Europe, but only the largest companies in the seed and plant breeding business have the financial capacity to go through the lengthy and costly procedure required for approving a GM crop variety. This hampers small and medium business and prevents business spin-offs from plant research.

Second, research priorities in regard to the environmental impacts of agriculture are not directed in a productive way; risk research in Europe is not helping to develop sustainable agriculture for the future. The paradigm that stipulates that biotechnology is inherently risky, and singles out one plant breeding technology as the basis for risk research, is putting a massive regulatory burden on a technology that could enhance sustainability. As a consequence, any future risk research on GMOs in Europe should address the costs of this burden and the risks of not using biotechnology. We conclude that the research programmes set up in the EU to address the potential risks of GM crops are no longer scientifically motivated inquiries. The scientific community has already settled the relevant questions regarding potential risks associated with GM crops approved under legislation; what is going on is a political game. In this game, the so-called precautionary principle is used, *in absurdum*, to delay any launch of a GM crop far beyond the limit of reasonable scientific doubts.

Third, it is time to acknowledge the distinct imbalance with respect to the costs and benefits of GM crops: lobbyists who benefit from demonizing GM crops are not the ones who have to carry the costs. Hence, it is not the hyped risks of GM crops that are a problem in the EU, it is the submissive attitude of politicians and policymakers towards organizations who insist that GM crops are risky. It is then ordinary consumers who pay the costs and do not receive the benefits. This submissiveness manifests in the prevailing policy that GM products should be kept separate from non-GM products, as well as the incessant calls for regulations about labelling and traceability. As shown above, the potential benefit to the European economy from adopting GM crops is substantial. But these potential

benefits vanish altogether when the costs of maintaining separation and consumer resistance are brought into play as a result of misinformation campaigns.

... research priorities in regard to the environmental impacts of agriculture are not directed in a productive way...

Risk research on GM crops in Europe has to come to an end, as do futile battles about disasters that will not happen. A dead parrot is a dead parrot, both in Monty Python sketches and in science. The way to sustainable and productive agriculture is not by maintaining expensive, parallel production systems, using different sets of crop varieties, and relying on expensive regulations for their coexistence. Instead, agricultural systems should use the best available technology at all stages, including plant breeding. It is clear that the approval and decision process within the EU for GM crops is not science-based. The risk assessment and approval process, where the outcome is dominated by the opinions of a few self-interested stakeholder organizations with special interests is unique. It is alarming that decision-making bodies *kow-tow* to this non-science-based paradigm.

ACKNOWLEDGEMENTS

J.F.S. and U.M. receive financial support from the Future Agriculture research platform at the Swedish University of Agricultural Sciences (SLU), C.D. is supported by the Swedish Research Council (VR) and SLU. We acknowledge Christer Andersson, Marie Nyman and Dirk-Jan de Koning for constructive comments on the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.


REFERENCES

- Berg P, Singer MF (1995) The recombinant DNA controversy: twenty years later. *Proc Natl Acad Sci USA* **92**: 9011–9013
- European Commission (2010) *A decade of EU-funded GMO research (2001–2010)*. Luxembourg, Belgium: Publications Office of the European Union
- Apel A (2010) The costly benefits of opposing agricultural biotechnology. *Nat Biotechnol* **27**: 635–640
- Guideline for the conduct of food safety assessment of foods derived from recombinant-DNA plants. Annex on the assessment of possible allergenicity* (2003). Rome, Italy: Codex
- Evaluation of the EU legislative framework in the field of cultivation of GMOs under Directive 2001/18/EC and Regulation (EC) No 1829/2003, and the placing on the market of GMOs as or in products under Directive 2001/18/EC (2011). Brussels, Belgium: EPEC
- Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions on the freedom for Member States to decide on the cultivation of genetically modified crops (2010). Brussels, Belgium: European Commission
- Hawes C *et al* (2003) Responses of plants and invertebrate trophic groups to contrasting herbicide regimes in the Farm Scale Evaluations of genetically modified herbicide-tolerant crops. *Phil Trans R Soc Lond B* **358**: 1899–1913
- Managing the footprint of agriculture: towards a comparative assessment of risks and benefits for novel agricultural systems. Report of the ACRE sub-group on wider issues raised by the Farm Scale Evaluations of herbicide tolerant GM Crops (2007). London, UK: ACRE
- Jardin P *et al* (2009) Applications (EFSA-GMO-RX-MON810) for renewal of authorisation for the continued marketing of (1) existing food and food ingredients produced from genetically modified insect resistant maize MON810; (2) feed consisting of and/or containing maize MON810, including the use of seed for cultivation; and of (3) food and feed additives, and feed materials produced from maize MON810, all under Regulation (EC) No 1829/2003 from Monsanto. *EFSA J* **1149**: 1–85
- Icoz I, Stotzky G (2008) Fate and effects of insect-resistant Bt crops in soil ecosystems. *Soil Biol Biochem* **40**: 559–586
- Fagerström T, Wibe S (2011) *Genvägar eller Senvägar*. Stockholm, Sweden: Elanders Sverige AB
- Qaim M (2009) The economics of genetically modified crops. *Annu Rev Resour Econ* **1**: 665–693
- Brookes G, Barfoot P (2011) *GM Crops: Global Socio-economic and Environmental Impacts 1996–2009*. Dorchester, UK: PG Economics Ltd
- Firbank LG, Petit S, Smart S, Blain A, Fuller RJ (2008) Assessing the impacts of agricultural intensification on biodiversity: a British perspective. *Phil Trans R Soc Lond B* **363**: 777–787
- Areal FJ, Riesgo L, Rodríguez-Cerezo E (2011) Attitudes of European farmers towards GM crop adoption. *Plant Biotechnol J* **9**: 945–957
- Kåhre L (1992) Växsorter i tiden. In *Växtodling*, pp 37–45. Uppsala, Sweden: SLU print
- Roos J, Hopkins R, Kvarnheden A, Dixelius C (2010) The impact of global warming on plant diseases and insect vectors in Sweden. *Eur J Plant Pathol* **129**: 9–19
- Rounsevell MDA, Berry PM, Harrison PA (2006) Future environmental change impacts on rural land use and biodiversity: a synthesis of the ACCELERATES project. *Environ Sci Pol* **9**: 93–100
- Garrett KA *et al* (2011) Complexity in climate-change impacts: an analytical framework for effects mediated by plant disease. *Plant Pathol* **60**: 15–30
- Varshney RK, Bansal KC, Aggarwal PK, Datta SK, Craufurd PQ (2011) Agricultural biotechnology for crop improvement in a variable climate: hope or hype? *Trends Plant Sci* **16**: 363–371
- Lusser M, Parisi C, Plan D, Rodríguez-Cerezo E (2011) *New Plant Breeding Techniques, State-of-the-art and Prospects for Commercial Development*. Luxembourg, Belgium: Publications Office of the European Union
- Schell J, Van Montagu M (1977) The Ti-plasmid of *Agrobacterium tumefaciens*, a natural vector for the introduction of nif genes in plants? *Basic Life Sci* **9**: 159–179
- Van Montagu M (2011) It is a long way to GM agriculture. *Annu Rev Plant Biol* **62**: 1–23
- Walsh G (2010) Biopharmaceutical benchmarks 2010. *Nat Biotechnol* **28**: 917–924
- Nowicki P *et al* (2010) *Study on the Implications of Asynchronous GMO Approvals for EU Imports of Animal Feed Products*. Wageningen, the Netherlands: European Commission



Torbjörn Fagerström, Christina Dixelius, Ulf Magnusson and Jens F. Sundström are at the Swedish University of Agricultural Sciences in Uppsala, Sweden.
E-mails: torbjorn.fagerstrom@slu.se; jens.sundstrom@slu.se

EMBO reports (2012) **13**, 493–497; published online 11 May 2012; doi:10.1038/embor.2012.59

 EMBO reports is published by Nature Publishing Group on behalf of European Molecular Biology Organization. This article is licensed under a Creative Commons Attribution Noncommercial No Derivative Works 3.0 Unported License [<http://creativecommons.org/licenses/by-nc-nd/3.0/>]