Genetically Modified Organisms: Non-Health Issues

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Synonyms

GMOs; herbicide tolerance; indirect harm; intellectual property; patents; Percy Schmeiser; research restrictions; feeding the world

Introduction

The controversy over genetically modified [GM] organisms is often framed in terms of possible hazards for human health. Articles in a previous volume of this *Encyclopedia* give a general overview of GM crops (Mulvaney 2014) and specifically examine human health (Nordgard, Gronsberg, and Myhr 2014) and labeling (Bruton 2014) issues surrounding GM organisms. This article explores several other aspects of the controversy: environmental concerns, political and legal disputes, and the aim of "feeding the world" and promoting food security. Rather than discussing abstract, hypothetical GM organisms, this article explores the consequences of the GM organisms that have actually been deployed in the particular contexts that they have been deployed, on the belief that there is little point in discussing GM organisms in an idealized or context-independent way.

Background

"Genetically modified" is sometimes regarded as an ambiguous term. A plant or other organism might be called genetically modified if it is *artificial*, that is, it has some of its traits as the result of an intentional human process. Nearly all commercially cultivated organisms are artificial, and humans have been producing artificial varieties of plants and animals (and fungi and bacteria) since the beginnings of agriculture. Alternatively, we might call an organism genetically modified if it is *genetically engineered*, that is, if it has been produced using techniques for the direct, molecular manipulation of its genome (or epigenome). More specifically, we could reserve the term "genetically modified" for *transgenic* organisms. These organisms contain a gene or gene complex from another species. For example, Bt or insect resistant [IR] crops are plants that contain genes from a bacterium *Bacillus thuringiensis*. When people worry about "GMOs," generally they are worried about either genetically engineered or specifically transgenic organisms, especially plants and animals. Since the majority of commercially-grown genetically engineered organisms today are transgenic, these two terms — while conceptually or logically distinct — are often extensionally equivalent. However, non-transgenic but genetically engineered organisms are at the center of some emerging regulatory controversies in the US and EU. Thus, in what follows, when this article refer to GM organisms, this article will mean organisms that are either genetically engineered or transgenic, not merely organisms that are the result of an intentional human process.

Globally, in terms of area under cultivation, about 59% of GM crops are herbicide tolerant [HT], 15% are Bt, and 26% are stacked, combining both HT and Bt. Other traits combined account for less than 1% of the use of GM crops. About 47% of GM crops are HT soybeans; maize (corn) makes up about 32%; cotton is about 14%; and canola is about 5%. Other species combined make up less than 1% (James 2012, Table 41). On November 19, 2015, the US FDA approved the commercial sale of a GM animal, the AquaAdvantage salmon. Until that point, all of the multicellular GM organisms that were approved for sale in the US were plants.

Environmental Concerns

There are several categories of potential environmental concerns arising from the deployment of GM organisms as food: 1) evolution of herbicide-tolerant and pesticide-tolerant plants and animals, 2) transmission of genes (outcrossing, gene flow) from GM crops to wild weedy relatives and to conventional crops, 3) increased use of herbicides and pesticides, 4) direct and indirect effects on other species and ecosystems.

Prior to the development of HT GM crops, it was known that weeds naturally varied in their response to herbicides such as glyphosate, with some very susceptible and others less so (i.e., some were naturally tolerant). Similarly, it was known that "pests" like the western corn rootworm naturally varied in their response to pesticides like Bt. Thus, it could have been predicted – and was predicted – that widespread use of herbicides and pesticides in conjunction with GM crops would act as a selective agent, killing the susceptible ones and in effect selecting for the tolerant ones, allowing the tolerant ones to flourish without competition. Indeed, this is what has happened. In 2012, the Weed Science Society of America website listed 22 Roundup-resistant weed species in the U.S.; Dow AgroSciences estimates that 100 million acres in the U.S. are already impacted by Roundup-resistant weeds. (Benbrook 2012). Similarly, western corn rootworms have evolved Bt resistance from their consumption of Bt corn (Gassmann et al.

2014). Thus, one environmental effect of the deployment of GM crops has been the evolution of herbicide-tolerant and pesticide-tolerant plants and animals. Some argue that this effect occurred because farmers failed to follow Monsanto's recommendation to plant "refuges," i.e., areas without GM crops. Refuges allow non-tolerant weeds/pests a place to flourish where they can interbreed with, and thus dilute the numbers of, tolerant weeds/pests. Recommendations call for 5%-20% of total land to be set aside as refuges, depending on the GM crop. However, blaming farmers for the evolution of weed/pest tolerance may not be taking into account the financial and practical contexts in which they find themselves; planting refuges means not only that farmers have to make a special effort to obtain non-GMO seeds, but also that they have to forgo short-term profits in favor of long-term ones.

Herbicide-tolerant weeds can also result from a different mechanism that has its origin in GM crops. When GM crops reproduce with closely related wild species, transfer of herbicide-tolerance to weeds can occur. Susceptible species include alfalfa, canola, sugar beets, and corn. Roundup Ready wheat (not on the market yet) was found to be six times more likely than non-GM control lines to produce outcrossed offspring (Rieben et al. 2011). These "transgenic weeds" could become difficult to manage, and possibly invasive (Greene et al. 2015). Similarly, there can be transmission of genes from GM crops to other, conventional (either non-GM or organic) crops. In a 2014 survey of 268 organic and non-GMO farmers in the U.S., 31 percent said that had found or suspected GMO presence in their crops. Of these, 52 percent said that they had been rejected by a buyer because of it (Food & Water Watch and Organic Farmers' Agency 2014). In Oaxaca, Mexico, one of the places where diverse strains of maize are found, researchers found "a high level of gene flow from industrially produced maize towards populations of progenitor landraces" (Quist and Chapela 2001). This is concerning because these maize strains might otherwise be used to create new commercial corn varieties; thus gene flow is affecting what might be considered a maize gene repository.

Increased herbicide tolerance, regardless of the mechanism that produced it, has led to an increased use of herbicides, even though one of the promises of GM crops was that they would reduce the use of herbicides. According to Charles Benbrook (2012), Roundup-resistant weed phenotypes are forcing farmers to increase herbicide application rates, make multiple applications of herbicides, and apply additional herbicide active ingredients. This is particularly significant in light of the World Health Organization's classification of glyphosate as "probably carcinogenic to humans," and thus, possibly carcinogenic to other species as well. Moreover, Dow has used evolution of Roundup-resistant weeds to argue for the deregulation of 2,4-D corn. 2,4-D is considered a more toxic herbicide, with a heightened risk of birth defects, more severe impacts on aquatic ecosystems, and more damage to nearby crops and plants (Benbrook 2012). On the other hand, the use of Bt corn has led to a reduction in pesticide use so far, but given the evolution of Bt tolerant pests (noted above), this reduction may be short lived.

As with humans (see Nordgard, Gronsberg, and Myhr 2014), there is currently no generally accepted evidence that animals that consume GM crops suffer direct health-related harms; more precisely, there is some laboratory evidence that Bt corn harms Monarch butterflies (Losey, Rayor, and Carter 1999), but no field evidence (Sears et al. 2001). However, AquAdvantage salmon – the first FDA-approved genetically engineered animal intended for food – creates the potential for another type of direct environmental harm. AquAdvantage salmon have been modified to grow at a faster rate (approximately twice as fast) than their non-modified counterparts, allowing them to be brought to market more quickly; critics have raised concerns about possible effects on other salmon, species that interbreed with salmon, and ecosystems more generally if the GM fish were to escape into the wild. Harm could occur, for example, if escaped AquAdvantage salmon or hybrids were considerably fitter than their non-GM counterparts – in a worst-case scenario, acting as an invasive species (Devlin et al. 2004). According to the FDA, precautions have been taken to prevent this:

> The AquAdvantage Salmon may be raised only in land-based, contained hatchery tanks in two specific facilities in Canada and Panama. The approval does not allow AquAdvantage Salmon to be bred or raised in the United States. In fact, under this approval, no other facilities or locations, in the United States or elsewhere, are authorized for breeding or raising AquAdvantage Salmon that are intended for marketing as food to U.S. consumers... the AquAdvantage Salmon are reproductively sterile so that even in the highly unlikely event of an escape, they would be unable to interbreed or establish populations in the wild. (U.S. Food and Drug Administration 2015)

Such precautions, supporters say, make any negative ecological consequences "virtually impossible" (Rack 2015). But it is widely acknowledged that a certain small percentage of the salmon will not be sterile (thus, the need for other sequestration methods). And once again, as in the case of Roundup-ready products, arguments in favor of GM deployment are assuming ideal conditions rather than the likely less-than-ideal conditions that can result from human error or unforeseen situations. Also, note that the FDA regulations do not and cannot prevent other countries from taking fewer precautions for AquAdvantage salmon sold in non-U.S. markets. Thus, despite precautions, there is some potential for direct harms from GM animals intended for consumption; although it is not the focus of this essay, similar concerns may be raised about GM animals modified for other purposes, such as mosquitos modified to reduce the spread of dengue or malaria (e.g., the consequences of the loss of a species of mosquitos from an ecosystem or the spread of lethal genes to related species).

Finally, there is some evidence of indirect harms to other species as a result of GM crops. One type of indirect harm includes possible impacts on populations of species that depend for survival or reproduction on the pests controlled (Wolfenbarger and Phifer 2000). A second type of indirect harm is exemplified by the increased spraying of Roundup that has led to a loss of milkweed habitat for Monarch butterflies and contributed to a major decline in the size of their populations (Pleasants and Oberhauser 2013). A third type of indirect harm is due to the fact that Roundup Ready corn seed is coated with neonicotinoid pesticides; neonicotinoids have been shown to affect bee reproduction (perhaps contributing to "colony collapse disorder") and to persist and accumulate in the soil (Goulson 2013). Although these claimed effects are somewhat controversial, neonicotinoids have been temporarily banned in the European Union, and the US's EPA says that it is "unlikely" to approve new outdoor neonicotinoid-pesticide uses without new data (Cressey 2015). Indeed, in January 2016, the EPA classified the neonicotinoid imidacloprid as very highly toxic to honey bees, citing effects such as reduction in number of worker bees available for foraging, reduction in foraging efficiency via sublethal effects on workers, decreased number or delayed development of brood either from direct exposure or indirectly from reduced brood feeding and maintenance by hive bees, and reduced fecundity and survival of queens.

Political and Legal Concerns

Especially in North America, many of the political and legal concerns surrounding GM crops stem (pun intended) from the control that intellectual property rightsholders enjoy over their use. In the US, new plant varieties can be protected by two different kinds of intellectual property [IP] rights. Sexually reproducing and tuber-propagated plants may be protected by a plant variety certificate under the Plant Variety Protection Act of 1970. This law contains exemptions that allow farmers to save seed and allow researchers to conduct research. General utility patents provide much more robust protection and control; the impacts of general utility patents on seed-saving and research will be discussed below. In the 2001 case *J.E.M. Ag Supply v. Pioneer Hi-Bred*, the US Supreme Court affirmed that GM plants are eligible for general utility patents (Janis and Kesan 2002).

It is also important to recognize that, since the 1980s, public funding for agricultural research in the US has been roughly flat, while private funding has roughly doubled (Fuglie and Toole 2014, Figure 1; see also Pray and Fuglie 2015). At the same time, at least one pair of researchers has argued that expanded intellectual property rights for GM plants have contribute to consolidation among plant biotechnology firms (Marco and Rausser 2008). A recent analysis of plant IP finds that the vast majority of certificates and patents are issued to a small number of large companies. In particular, DuPont "holds more gene patents than Monsanto or the rest of the US industry … put together" (O. A. Jefferson et al. 2015, 1140). All together, these trends suggest that researchers and farmers are both more dependent on multinational seed-biotechnology firms than in the past.

The Schmeiser Case

One common concern about GM crops is that agricultural biotechnology giants — especially Monsanto — routinely use their intellectual property rights to sue farmers. The basic worry here is that farmers face expensive lawsuits, financial liabilities, and (in the case of organic farmers) loss of organic certification, even in cases of "accidental contamination," where GM seeds grow as weeds on farmers' land. More generally, the concern is that intellectual property rights attached to GM crops give large corporations significant economic power over farmers.

These concerns frequently trace back to the Canadian case *Monsanto Canada v. Schmeiser*. Percy Schmeiser is a conventional (non-organic) canola farmer in Saskatchewan. In the 1990s, Schmeiser routinely saved seeds from one year to use in planting the next year's crop. Somehow — Schmeiser claimed it must have been accidental, but the point was controverted by Monsanto — GM canola that was resistant to Monsanto's herbicide glyphosate (Roundup) came to grow on Schmeiser's land. Schmeiser identified the herbicide-resistant canola through a series of sprayings and plantings, and by 1998 nearly all of the canola growing on Schmeiser's land was Roundup resistant. Based on the fact that Schmeiser had saved and replanted patented seed, Monsanto sued for patent infringement in 1998. The Federal Court of Canada decided in Monsanto's favor in 2001 (2001 FCT 256), and this judgment was upheld by the Canadian Supreme Court in 2004 (2004 SCC 34).

Monsanto and its defenders argue that the Schmeiser case does not provide a precedent for accidental contamination lawsuits. First, while it is not clear how the GM canola first came to grow on his property, nor what his ultimate intentions were, it is clear that Schmeiser was deliberately cultivating it: several times over, he sprayed a plot of land with glyphosate, then saved and replanted the seeds from the plants that survived. Monsanto's complaint was that Schmeiser identified, saved, and replanted the GM canola, not that it first appeared on his property by accident. As the Federal Court of Canada judge put it in her ruling, Schmeiser's "infringement arises not simply from occasional or limited contamination of his Roundup susceptible canola by plants that are Roundup resistant. He planted his crop for 1998 with seed that he knew or ought to have known was Roundup tolerant" (2001 FCT 256, at 125). Saving and reuse, not accidental contamination, was also the issue in *Bowman v. Monsanto* (USC 2010-1068), a similar case in the US.

Second, Monsanto has stated on several occasions that it will not sue farmers in accidental contamination cases. "Monsanto's Commitment: Farmers and Patents," a document on the company's website, states that "It has never been, nor will it be Monsanto policy to exercise its patent rights where trace amounts of our patented seed or traits are present in farmer's fields as a result of inadvertent means" ("Monsanto's Commitment: Farmers and Patents" 2015). In 2013, Monsanto used this argument to defeat a class-action lawsuit from a group of organic farmers, who were concerned that Monsanto might sue them for patent infringement in the future (*Organic Seed Growers and Trade Association, et al. v. Monsanto Company, et al.*, USC 2012-1298).

However, there are reasons why some people might still have concerns about accidental contamination and other patent infringement lawsuits. First, "Monsanto's commitment" is not legally binding on Monsanto, much less any other large agricultural biotechnology company (compare Ma 2012, 716). Second, the rulings in Schmeiser's case rejected arguments that would likely be used by defendants in accidental containment suits. For example, Schmeiser attempted to argue "that there was no intention to infringe the patent" (2001 FCT 256, at 115). However, the Federal Court of Canada judge found that

> it is well settled that infringement is any act which interferes with the full enjoyment of the monopoly rights of the patentee . . . . Further, intention is immaterial, for "infringement occurs when the essence of an invention is taken," regardless of the intention of the infringer. (2001 FCT 256, at 115; see also Ma 2012, 703)

Schmeiser also attempted to argue that because the 1998 canola crop was never sprayed with Roundup, he "did not make use of the invention as the inventor intended and so, did not use the patented gene or cell" (2001 FCT 256, at 121). In response, the judge argued that

> In my opinion, whether or not that crop was sprayed with Roundup during its growing period is not important. Growth of the seed, reproducing the patented gene and cell, and sale of the harvested crop constitutes taking the essence of the plaintiffs' invention, using it, without permission. In so doing the defendants infringed upon the patent interests of the plaintiffs. (2001 FCT 256, at 123)

In other words, the conditions under which the GM crops were grown are irrelevant. Merely growing patented plants might be sufficient for a successful infringement suit, if Monsanto or another rightsholder holder someday decides to start filing accidental contamination suits. (For an argument in favor of allowing unintentional infringement suits, see Janis and Kesan 2002.)

Furthermore, when it comes to deliberate infringement cases — cases where a farmer has signed a license agreement with Monsanto but saved seed anyway — critics argue that Monsanto uses excessively heavy-handed and intimidating tactics. The Center for Food Safety, a nonprofit organization that is opposed to GM crops, claims that "Monsanto investigators have taken samples from farmers' lands without permission and without notice, have staked out farm supply store owners' property and have warned customers against doing business with the accused owners, and have utilized aggressive physical and emotional tactics to gain an upper hand during investigations or in court" (as summarized by Ma 2012, 702). Using public records, the Center for Food Safety found that "As of November 28, 2012, Monsanto had filed 142 lawsuits against farmers." In addition, the Center for Food Safety estimated that Monsanto has pursued between 2,391 and 4,531 patent violation cases against farmers, collecting pretrial settlements between $85 and $160 million (Kimbrell and Mendelson 2012). However, these estimates are allegedly based on regional fact sheets that were removed from a Monsanto website sometime in 2006-2007.

Philosophically speaking, many of these concerns about patent infringement might be usefully analyzed in terms of trust and trustworthiness. Monsanto claims that it will never bring suit for patent infringement in accidental contamination cases. However, based on claims that Monsanto uses heavy-handed tactics in deliberate infringement cases, some farmers and other critics believe that Monsanto's primary motive is its own bottom line, and so it does not have the good will towards farmers that trust requires (compare Baier 1986; see also Scheman, Jordan, and Gust 2011; Scheman 2011).

Research Restrictions

Some groups of scientists have expressed concerns about the use of intellectual property rights to restrict independent research. In February 2009, a group of 24 entomologists submitted a short public comment to the EPA's FIFRA SAP (an external oversight and advisory body that covers, among other things, the agency's pesticides program, which regulates certain GM crops) (E. Shields 2009). The scientists argued that the license agreements required to purchase patented GM seeds prohibited independent research, with two harmful effects. First, they "inhibit public scientists from pursuing their mandated role on behalf of the public good unless the research is approved by industry"; that is, scientists could only develop the technology further — say, developing varieties that were well-suited to the growing conditions of a certain place — with the rightsholder's permission. Second, "no truly independent research can be legally conducted on many critical questions regarding the technology, its performance, its management implications, IRM [insect resistance management], and its interactions with insect biology." In other words, there was no (legal) independent research on the effects of GM crops on non-target insects such as butterflies or the evolution of pesticide resistance. Just over a year later, a longer discussion of these issues was published as a commentary in the journal *GM Crops* (Sappington et al. 2010).

In response to these concerns, the American Seed Trade Association [ASTA] "negotiated an agreement between university scientists and seed companies to protect industry property rights while enabling university scientists to conduct research with more independence" (Glenna et al. 2015, 151; see also Sappington et al. 2010, 2). A recent survey of entomologists found that 63% of all respondents (N=38) were either satisfied or very satisfied with the ASTA agreement; however, among public-sector researchers (N=29), 31% agreed that their "research on the efficacy or environmental impact of a genetically engineered crop had ... been hindered by an industry partner," and 59% agreed that "[i]f there were no bag-tag restrictions on university research, [they] would ... conduct research on the efficacy or environmental impact of a genetically engineered crop" (Glenna et al. 2015, tables 1 and 2, 160-1). The team that conducted this survey interpreted these results as evidence that "these entomologists think that the ASTA agreement is better than the previous arrangements, even though many still believe that the intellectual property protections create obstacles for research" (161, 166). In a free-response section of the survey, respondents raised concerns that industry partners can restrict access to junior researchers or scientists whose findings they do not like (163-4) and create bureaucratic delays that discourage research and publishing findings (162). All together, the team concluded that "intellectual property protections in GE crops are hindering some types of agricultural and environmental research" (166).

The philosopher of science Justin Biddle has also raised several concerns about the ASTA agreement (Biddle 2014, 19). First, the agreement covers only scientists at about 100 US research universities, and no scientists outside of the US. In addition, the agreement does not include certain areas of research. Research for "detecting the presence or absence of patent-protected traits" is explicitly not included, and it is not clear whether research on health effects is included. Further, the agreement is voluntary and "the seed company ... can revise or completely abandon the agreement at any time." And finally, agreements or academic licenses are developed on a company-by-company basis, although the American Seed Trade Association has developed a set of "principles and objectives" for these agreements ("Research with Commercially Available Seed Products" 2009).

Feeding the World

One of the most popular arguments for the development and use of GM crops is their value for "feeding the world": that is, for improving food security, especially given a growing world population and the potential effects of climate change. For example, a "communicator's guide" prepared by an agricultural biotechnology industry organization identifies feeding the world as one of its four "key messages" (*Food Biotechnology: A Communicator's Guide to Improving Understanding* 2013).

The impacts of GM crops on yields have been heavily studied by both agronomists and agricultural economists for about 20 years. Until recently, the only summaries of this body of research were review reports, which generally did not include detailed discussions of their literature search and statistical methods. One such review report is Doug Gurian-Sherman's "Failure to Yield" (Gurian-Sherman 2009), produced and released under the auspices of the Union of Concerned Scientists. Gurian-Sherman holds a Ph.D. in plant pathology from UC Berkeley. This report continues to be widely cited by GM critics both online and — to a lesser extent — in some scholarly writing. Gurian-Sherman estimated that HT maize had not seen increased yields, and that Bt maize had seen increased yields between 7% and 12%, but only when insect pests are present (Gurian-Sherman 2009, 2–3).

Another widely-cited review report was prepared by Janet Carpenter, an agricultural economist (Carpenter 2010). This report was supported by CropLife International, an agricultural biotechnology industry organization. Carpenter estimated that GM crops are 0-7% more productive in developed countries, and 16-85% in developing countries (Carpenter 2010, table 2).

Neither Gurian-Sherman nor Carpenter explained their methods in detail. At best, their findings depend heavily on their ability, as experts, to perceive the essence or truth underlying the data (Daston and Galison 2007, ch 2). At worst, they're selecting the findings that best support the political and economic interests of their sponsors. Elsewhere, one of us argues that the disagreement between Gurian-Sherman and Carpenter extends to deep views about the aims of scientific research: Gurian-Sherman cited carefully controlled experimental studies, with the potential to prove causal relationships, while Carpenter cited surveys of farmers that would provide a better basis for extrapolation (Hicks 2015).

In the last few years, groups of agricultural economists have undertaken meta-analyses of the primary research on GM crop yields. Meta-analyses are similar to review reports, in that they summarize the findings of a large body of primary research. But meta-analyses generally involve a systematic search of the literature and more sophisticated statistical techniques, and these methods are usually described in some detail when the meta-analysis is published. Whereas review reports depend on expert perception, meta-analysis presents itself as approximating an ideal of mechanical objectivity (Daston and Galison 2007, ch 3).

As far as the authors of this article are aware, the first meta-analysis of GM crop yields was prepared by Finger et al. (2011). They focused on maize (corn) and cotton, primarily Bt varieties; much of their data come from India, China, Spain, South Africa, the US, and Argentina. They found that Bt cotton had a statistically significant greater yield in India than conventional cotton; the difference was not statistically significant for the other countries. They did not find a statistically significant difference in yields for maize in any country.

The Finger et al. meta-analysis has not been highly cited. A more high-profile study was published in 2014 in *PLoS ONE* by Klümper and Qaim (2014). Klümper and Qaim examined data for Bt and HT varieties of maize, cotton, and soybeans. They found that IR crops were associated with 25% greater yields, while HT crops were associated with 9% greater yields.

Both of these meta-analyses provide details about their literature search and construct statistical models to control for other factors that influence yields. However, the epistemic quality of a meta-analysis is limited by the epistemic quality of the primary research that it summarizes. And there are some notable limitations in the primary research on GM crop yields.

First, some of this primary research does not include measures of variance, and sometimes even sample sizes are not reported. In other areas, such as biomedical research, these statistics are considered necessary for including a piece of primary research in a meta-analysis. Klümper and Qaim acknowledged this limitation (5), but it's unclear whether it's a small problem (with just a small number of studies) or a large one (affecting many studies). In personal communication, Matin Qaim declined to clarify the magnitude of the problem.

Second, much of the data (206 out of 451 findings, or nearly 46%) come from studies conducted in developing countries concerning Bt cotton. By contrast, this research includes very little data on soybeans in developing countries (9 findings) and there does not appear to be any data for stacked maize as such. And yet the majority of maize grown in the US is stacked, and effectively all of the soybean crop in Argentina is Bt. [James (2012), 47, estimates 20.2 MHa of GM soybeans in Argentina in 2012; Markley (2012), 2, estimates 18.8 MHa of total soybean cultivation. MHa is millions of hectares; 1 MHa is 10,000 square kilometers or about 3,900 square miles. 20 MHa is about half of the total area of Germany.] This raises both statistical and epistemic concerns. Statistically speaking, the overall means reported above are based on biased samples: they oversample cotton in developing countries, undersample soybeans in developing countries, and do not include stacked maize at all. Without statistically correcting for this bias, the overall means may not be reliable. Klümper and Qaim did construct a model that corrects for this bias, but the results highlighted in their abstract — and reported above — are based on an uncorrected mean. In addition, it is unclear whether these data give us a good basis for extrapolation. We have a large amount of evidence concerning the productivity of Bt cotton in developing countries, and some evidence concerning HT soybeans in developed countries (65 findings), and a very small amount of evidence for HT maize (2 findings) and soybeans in developing countries. What do these data tell us about HT soybeans in Argentina? Can the data for Bt and HT maize to make predictions about stacked maize somehow be combined? Philosophers of science have raised concerns about extrapolation and meta-analysis in other contexts (Stegenga 2011; Douglas 2012); they seem to be of particular relevance here.

Summary

While the controversy around genetically modified organisms often focuses on human health concerns, there are also a variety of environmental, political, legal, and social issues at play. Major environmental issues include the evolution of pesticide-tolerant organisms, gene transmission, the impact of GM crops on pesticide use, and direct and indirect effects on other species. Political and legal concerns often involve the power that intellectual property rightsholders have to restrict the activities of farmers and researchers. Finally, there are significant scientific controversies over the value of GM crops for addressing food security.

Cross-References

- Biotechnology and Food Policy, Governance
- Economy of Agriculture and Food
- Ecosystems, Food, Agriculture, and Ethics
- EU Regulatory Conflicts over GM Food
- GM Food, Nutrition, Safety, and Health
- GMO Food Labeling
- Human Ecology and Food
- Intellectual Property and Food
- Intellectual Property Rights and Trade in the Food and Agricultural Sectors
- Pest Control
- Political Agronomy
- Population Growth
- Saving Seeds
- Sustainability of Food Production and Consumption
- The 2003–2006 WTO GMO Dispute: Implications for the SPS Agreement

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