Why so much controversy over genetically modified organisms? Answers to 10 frequently asked questions about GMOs

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Introduction

At the threshold of the 21st century, global agriculture finds itself gripped in an acrimonious debate over genetically modified organisms (GMOs). This debate, which features a volatile mix of science, economics, politics, and ethics, is taking place in research laboratories, corporate boardrooms, legislative chambers, newspaper editorial offices, Main Street coffee shops, and private homes—in short, nearly everywhere people grow, process, consume, or even just talk about food. In Britain, Prince Charles publicly and repeatedly states his opposition to GMOs, commonly referred to by the British press as "Frankenstein food." In Mexico, hooded activists scale the Angel of Independence monument in the capital and hang banners protesting imports of transgenic corn. In India, protesters storm agricultural experiment stations and uproot test plots containing genetically modified plants. In Italy, naked protestors drenched in red paint to simulate blood hurl genetically engineered tomatoes at the visiting US Secretary of Agriculture to demonstrate their opposition to imports of transgenic corn and soybeans.

What explains these widespread and highly publicized protests? Why have GMOs suddenly become a lightning rod for public debate? Are proponents of GMOs justified in saying that genetic modification of plants and animals is nothing more than the latest in a long series of productivity-enhancing technologies that have helped the world's food supply keep pace with global population growth? Or are the critics correct in arguing that GMOs are fundamentally different from other types of organisms—so different that they must be banned immediately, with no further testing to determine their safety?

In this article, we attempt to shed light on the controversy by addressing 10 basic questions about GMOs. We conclude that GMOs could potentially generate substantial benefits, but we caution that public opposition is likely to continue until questions are resolved concerning their safety for people, animals, and the environment. In addressing these questions, it will be important to foster an open, inclusive public dialogue based on scientifically validated information and to avoid getting sidetracked by politically motivated rhetoric.

1. What is a GMO?

GMOs are living organisms (plants, animals, or bacteria) that have been genetically "engineered" by the insertion of a foreign gene. The foreign gene, which can come from any one of a number of different sources, is inserted to increase the value of the recipient organism. Genetically modified crops, the focus of this article, are usually designed to do one of two things: (1) lower farm-level production costs (e.g., by making plants resistant to pests and diseases) or (2) enhance product quality (e.g., by increasing the crop's appearance, nutritional content, or processing and storage characteristics). GMOs are created using biotechnology, but it is important to recognize that GMOs and biotechnology are not the same thing. The term "biotechnology" encompasses a large field of research, of which the production of GMOs makes up only one part.

2. How are GMOs produced?

GMOs are produced through a process known as genetic engineering, in which genes that code for desirable traits are transferred from one organism to another. Genetic engineering begins with the identification of the gene responsible for a trait of interest. (Many economically useful traits in fact are controlled by multiple genes, but for simplicity this discussion refers to traits that are controlled by a single gene.) After such a gene has been identified and isolated, it can be inserted into a cell—in this case, the cell of a crop plant—using one of several techniques. Perhaps the most widely known technique involves literally shooting the gene using a "gene gun," a device that uses bursts of helium to propel microscopic particles coated with many copies of the gene directly into the receptor cell. A second commonly used technique uses a bacterium called *Agrobacterium tumefaciens* as a living vector.

Regardless of which transformation method is used, the foreign gene is inserted randomly along one or more chromosomes in the receptor cell. Since not every receptor cell receives a copy of the inserted gene, it is necessary to identify those cells that have been successfully transformed. This is done by first growing the receptor cells on a series of special selective growth media and then on media that induce them to form plantlets, many of which eventually develop into normal plants. These plants are screened to determine whether the foreign gene is present and functioning properly. Once a gene has been successfully inserted into one plant, it is usually much easier to move it into other plants through conventional plant breeding techniques. For example, as soon as one transgenic insect-resistant corn plant has been produced through genetic engineering techniques, by crossing that plant to other corn plants, it is possible to transfer the insect resistance trait.

3. Why are GMOs so controversial?

In some respects, genetic engineering is not much different from other types of genetic manipulation that are routinely carried out to create organisms with desirable characteristics. After all, conventional plant breeding also involves the controlled transfer between organisms of genes that code for economically valuable traits. Where genetic engineering differs from conventional breeding, however, is in allowing genes to be transferred more easily across taxonomic boundaries. With genetic engineering, genes can be transferred not only between closely related organisms (for example, when a gene coding for disease resistance is transferred from a wheat plant to a rice plant), but also between completely different organisms (for example, when a gene coding for cold tolerance is transferred from a fish to a strawberry plant). In conventional breeding, biological reproductive processes impose limits on genetic recombination by erecting barriers against successful crossing between biologically distinct organisms; either the crossing fails completely, or else the progeny are sterile. With genetic engineering, the "natural" limits do not always have to be respected. For this reason, some people consider GMOs to be "unnatural" organisms that violate the laws of nature. Others consider this distinction arbitrary, countering that most foods consumed today have been radically modified over thousands of years through deliberate selection or accidental mutation.

One curious feature of the public debate over genetic engineering is that frequently different standards are invoked for different categories of GMOs. Some of the most vociferous critics of genetically modified food crops seem unperturbed by the fact that many widely used pharmaceutical products are also genetically engineered. For reasons that are not entirely clear, the same people who argue that genetically modifying food crops is tantamount to "playing God" often fail to raise similar objections regarding the use of genetic engineering techniques to produce insulin, human growth hormone, and many commonly used drugs. Similarly, ethical objections to genetic engineering are rarely voiced in relation to GMOs used for industrial purposes, such as the transgenic oil-eating bacteria that are used to process certain types of industrial waste.

4. Who produces GMOs?

The potential benefits of genetically modified crops have not gone unnoticed by the companies that produce and sell agricultural inputs. Most of the leading life sciences companies that dominate the seed market are investing in genetic engineering of crops. In contrast to conventional plant breeding, which is carried out worldwide, most of the research on transgenic crops has been carried out in industrialized countries, mainly in North America and Western Europe (more recently, many developing countries have also established genetic engineering research capacity). Not surprisingly, research on transgenics has focused on crops of economic importance in these countries, including soybean, corn, cotton, canola, potato, and tobacco.

Key players in the US$ 23 billion global seed industry include DuPont/Pioneer, Monsanto/Pharmacia & Upjohn, Novartis, Aventis, Groupe Limagrain, and Advanta, whose combined revenues totaled over US$ 5.6 billion in 1997. These highly visible multinationals represent only the tip of the industry iceberg, however, as the market leaders are supported by hundreds of smaller research firms, specialized equipment manufacturers, and university labs on whom they rely for key products and services.

5. Where are GMOs currently being grown?

Research on genetically modified crops began decades ago, but only recently have transgenic crops reached the deployment stage. In the early 1990s, China became the first country to introduce a commercial GMO, a virus-resistant tobacco variety. In 1994, a delayed-ripening tomato developed by Calgene, the well-known Flavr-Savr™, became the first genetically modified food crop to be produced and consumed in an industrialized country. During the past few years, genetically modified crops have found their way into farmers' fields with increasing frequency and are today being grown in many developed and developing countries.

Generally speaking, most of the farmers who have tried transgenic crops have been pleased with their performance. The rapidly accelerating adoption rate provides a good indicator of the acceptance of transgenics among the farming community. Not counting China, the area planted to transgenic crops shot up from 1.7 million ha in 1996 to 11.0 million ha in 1997 to 27.8 million ha in 1998 (James 1998). Global sales of transgenic crops have risen at a similar rate, rising from US$ 235 million in 1996 to US$ 670 million in 1997 to US$ 1.5 billion in 1998 (James 1998).

6. What are the potential benefits of GMOs?

(a) Increased productivity

Most of the transgenic crops currently being grown feature traits that are designed to increase farm-level productivity, either by reducing input use or by raising crop yields. Probably the best-known example of an input-reducing transgene is Bt, a gene from a soil-borne bacterium called *Bacillus thuringiensis* that induces plants to produce a protein toxic to several common insect pests. Bt crops are widely grown, accounting for an estimated 7 million ha of corn and 1 million ha of cotton in 1998 (James 1998). Despite a relative paucity of performance data, already it has become clear that the host plant resistance conferred by Bt can significantly increase yields and/or reduce the need for chemical pest control. Based on field trials conducted in the US, Koziel et al. (1993) estimate yield gains of up to 8% in Bt corn (in the absence of insect pressure, the yield advantage would of course be lower). James reports reductions in the amount of insecticide applied of up to 40% in potato. For most farmers, reduced use of pesticides translates directly into higher profits—between US$ 7-36 per ha for corn in the US (Carlson, Marra, Hubbell 1997). These short-run benefits do not include the environmental benefits that are expected to occur over the long run through reduced pesticide use.

A second well-known example of an input-reducing transgene is the gene that provides resistance to glyphosate herbicide. This gene has been used by Monsanto to develop glyphosate-resistant varieties of cotton, soybeans, and corn. Sold under the brand name Roundup Ready, these varieties have proved popular with farmers. Herbicide-tolerant crops, mainly Roundup Ready varieties, account for an estimated 15 million ha of soybeans, 2 million ha of canola, and 2 million ha of corn in 1998 (James 1998). A single application of Monsanto's Roundup herbicide is usually sufficient to achieve effective control of broadleaf weeds, reducing the need for multiple herbicide applications. Although the cost savings associated with herbicide resistance are highly variable, preliminary data from the US suggest that Roundup Ready soybeans increase farmer's profits by an average of US$ 14 per ha (Carlson, Marra, Hubbell 1997).

(b) Enhanced quality

Many "first-generation" transgenic crops have proven their ability to lower farm-level production costs. Current research is focused on "second-generation" transgenics that will feature enhanced nutritional and/or industrial qualities. Plant breeders have long been trying to develop crop varieties with added vitamins and minerals; following recent breakthroughs in genetic engineering methods, progress on this front is expected to accelerate dramatically. Nutritionally fortified crop varieties should prove especially valuable in developing countries, where millions of people suffer from dietary deficiencies. The benefits will not be restricted to the developing world, however.

Nutritionally enhanced crops should also prove attractive in industrialized countries as a means of reducing consumption of unhealthy oils, proteins, and starches. Soybean and canola varieties have already been engineered to produce healthier oils containing reduced levels of fatty acids.

Nutritionally enhanced GMOs will benefit not only humans, but also animals. Work is underway to engineer feed crops with high nutritional value. Genetically engineered feed crops may have a role to play in increasing feed conversion ratios, as researchers believe that if they can match an animal's feed amino acid composition with that of its own amino acid balance, then there is potential to lower overall feed requirements and reduce pollution from animal waste. Animal health specialists are even examining the possibility of engineering feed crops capable of delivering vaccinations against common diseases.

7. What are the potential risks associated with GMOs?

(a) Human health

Opponents of genetic engineering have focused on the potential threat posed by GMOs to human health. While there is no evidence to show that any of the transgenes found in genetically modified foods are injurious to humans, one frequently mentioned concern is that widespread human consumption of genetically modified foods might lead to an increase in diseases resistant to several types of broad-spectrum antibiotics. This concern arose because the plasmid vectors on which foreign genes are inserted frequently also contain antibiotic resistance genes (although these genes were not expressed). Some health specialists worried that if these genes were present in transgenic foods in excessively high levels, they would build up in the bodies of consumers and lead to an increase in diseases resistant to antibiotics. More recently these concerns have been allayed in that researchers have devised transformation techniques which avoid the use of plasmid vectors containing antibiotic resistance genes.

Another potential risk posed by GMOs is that people with allergies could suffer reactions after unwittingly consuming genetically modified foods containing allergenic proteins introduced from external sources. In other words, someone who is allergic to peanuts might suffer a reaction after consuming transgenic soybeans that had been modified by the insertion of the peanut gene that produces the allergic reaction. Since very few genes produce harmful compounds, the risk of this happening is extremely low. And even if an inserted gene were to result in production of a harmful compound, the chances of it ever reaching the consumer are negligible, considering the rigorous food safety tests that all new products (including GMOs) must undergo.

(b) Animal health

Some of the concerns over the potential threat posed by GMOs to human health have also been raised regarding animal health. Since livestock and poultry consume large amounts of corn and soybeans, commodities that are likely to be genetically modified, the prospect of antibiotic resistance has been raised by some livestock producers. Should GMOs lead to a buildup of antibiotic resistance, this could increase the cost of maintaining animal health, since commonly used antibiotics might become ineffective. Concerns have also been expressed that antibiotic resistance could be passed on to people who consume livestock products. To date, no evidence has emerged to show that consumption of genetically modified feeds has affected animal health. Such feeds have not been around long enough for long-term feeding trials to have been carried out, so it may be premature to conclude that the issue has been definitively resolved. But the fact that transformation techniques are no longer based on antibiotic resistance genes suggests that if problems have not been detected thus far, they are unlikely to emerge in the future.

(c) Environmental impacts

Probably the single most controversial issue surrounding GMOs is their long-term impacts on the environment. Although it will not be possible to do justice here to this complex topic, a number of specific concerns must be mentioned.

One obvious risk associated with the use of any crop (transgenic or otherwise) that has been bred for insect resistance is the possibility that the targeted insects will eventually develop resistance to the toxins produced by the crop. In the case of genetically modified Bt crops, some environmentalists have argued that resistance is likely to emerge fairly quickly, since insects will be continuously exposed to Bt-produced toxins. Indeed, a number of common insect species, including such important crop pests as the Colorado potato beetle and the diamondback moth, have already developed resistance to Bt (it is important to note, however, that this resistance has resulted from exposure to Bt sprays, not to transgenic Bt crops). This finding has raised questions about the longevity of the insect resistance offered by genetically modified crops and led some to question whether the costs of producing such crops will justify the benefits.

Another risk linked to the potential emergence of resistance in insects is that Bt might lose its effectiveness as a topical pesticide. Bt-based pesticides are used to control pests in a number of fruit and vegetable crops. Since Bt is naturally occurring, these pesticides are especially popular among organic farmers. If the widespread planting of transgenic Bt crops were to foster the emergence of Bt-resistant insects, farmers who currently rely on Bt-based topical pesticides could suffer important losses. The emergence of Bt-resistant insects could of course also occur from overuse of Bt sprays, although this possibility is considered less likely, since with Bt sprays the exposure to the toxins is less continuous.

Whether incorporated directly into transgenic plants or applied as a topical pesticide, in order to maintain its usefulness over the long term Bt will have to be used as part of an integrated pest management (IPM) strategy. One strategy for slowing the emergence of Bt resistance is to increase the toxicity of transgenic plants, either by increasing the dosage of toxin present in the plant or by pyramiding several different types of Bt genes to produce a cocktail of natural toxins. Another strategy involves the use of insect refugia, areas free from transgenic crops in which normal non-resistant insects can continue to live. These non-resistant insects can continue to mate with those exposed to the Bt crops, ensuring that susceptibility is maintained in the overall population. In the

US, the companies that sell Bt crops now recommend that farmers maintain 20% of their cropped area as refugia and use conventional insect control in these refugia to ensure the survival of non-resistant insects. As of today, the jury is still out as to whether or not the refugia strategy will work. Farmer compliance could potentially become a problem, because if transgenic crops are significantly more profitable, there will be strong incentives for farmers to cheat by not planting refugia.

In contrast to those who worry that Bt crops may not be effective enough, others worry that they will be too effective, in the sense that they will kill insects other than the targeted pests. The highly publicized Cornell University monarch butterfly study, which showed a heightened mortality rate among monarch larvae fed transgenic Bt corn pollen, raised the possibility that non-pest insects could be harmed (Losey, Rayor, Carter 1999). Since the Cornell study was published, researchers at Iowa State University have cautioned against extrapolating the findings, which were obtained under laboratory conditions that appear very different from actual field conditions faced by wild monarchs (Rice 1999). Efforts are currently underway to evaluate this danger in the field.

While much attention has been focused on the possible environmental risks posed by insect resistance, concerns have also been raised about the use of herbicide resistance. The primary danger here is that herbicide-resistance genes could jump from transgenic crops to other wild or domesticated species, producing "super weeds" that would resist conventional control methods. In order to control these super weeds, farmers might have to switch to more powerful and potentially more environmentally damaging herbicides. This concern is valid, as numerous studies have shown that genes can flow from domesticated crops through unintentional outcrossing with plants growing in neighboring fields. On the other hand, the threat posed to the environment probably varies a great deal from one location to the next, depending in part on the species that are present. For example, although there will always be some possibility of genes jumping from transgenic corn to non-transgenic corn growing in nearby fields, the likelihood of unintentional transfers to wild relatives will vary considerably. In Africa or Asia, there would be little likelihood of herbicide resistance jumping from corn to a wild relative;

corn is not native to these regions, so there are no wild relatives. In Mexico and Central America, however, the threat would be much greater, since the wild relatives from which corn was originally domesticated are still present.

8. Why do attitudes about GMOs differ so much around the world?

One interesting feature of the debate over GMOs is the sharp contrast in public attitudes from one country to the next. The Atlantic Ocean in particular represents a major fault line: GMOs seem to have been tacitly accepted in the US, whereas they have inspired widespread protests in many parts of Europe. The pronounced difference in attitudes appears to be attributable to two main factors. First, consumers on either side of the Atlantic differ greatly in their trust of food safety regulation systems. Americans in general have faith in their government's ability to protect them from unsafe food products. US regulatory organizations are widely supported; 90% of Americans support the USDA, and 84% support the FDA. In Europe, on the other hand, attitudes are very different. European regulatory agencies are viewed with suspicion; only 4% of Europeans say national public bodies can be counted on to tell the truth about transgenic crops (Gaskell, Bauer, Durant, Allum 1999). This low level of support no doubt stems at least in part from a series of recent incidents in which regulatory agencies initially failed to detect the seriousness of a food safety problem and then tried to downplay its likely consequences, such as the "mad cow" disease outbreak in Britain and the Belgian poultry scandal.

A second factor that has contributed to the variability in public attitudes is the differential availability of food content information. European consumers tend to pay a lot of attention to the foods they eat and insist on knowing about its provenance. Partly for this reason, European retailers are required to label products that contain GMOs, which in addition to providing important information to consumers has also served to alert them to the proliferation of genetically modified foods. American food manufacturers are not required to label genetically modified foods and have fought hard (with support of the farm lobby) to prevent such labeling. As a result, most American consumers are not aware that many of the products they consume contain genetically modified ingredients. This lack of information—which some would say leads to dangerous ignorance—has certainly contributed to the relatively complacency of American consumers.

9. Are GMOs appropriate for developing countries?

Although the public debate over GMOs has taken place mainly in the North, the South has an important stake in the outcome (Nuffield Council on Bioethics 1999). Many developing countries still depend heavily on agriculture, so they stand to benefit disproportionately from any technology that can increase food production, lower food prices, and improve food quality. Prince Charles may be right when he says that GMOs are unnecessary in Britain, where the cost of raw commodities makes up a small fraction of the final price paid by consumers for heavily processed, elaborately packaged, and extensively advertised foods, but it is hard to make the same argument in developing countries where millions go to bed hungry every night because food is unavailable or unaffordable. In places where there is often not enough food to go around and where food prices directly affect the incomes of a large proportion of the population, the potential productivity gains offered by GMOs cannot easily be ignored. The same argument that can be made in favor of the potential productivity gains associated with transgenics can also be made regarding potential quality improvements: nutritionally enhanced foods may not be urgently needed in most industrialized countries, where the vast majority of consumers have the possibility of meeting minimum daily nutritional requirements, but they could play a key role in many developing countries in helping to alleviate malnutrition. Transgenic crops are not currently being grown in many developing countries, so it is difficult to predict their eventual worth, but ex-ante economic evaluation studies suggest that GMOs are likely to bring considerable benefits to farmers and consumers (Qaim 1998, 1999).

If the potential benefits of GMOs are disproportionately large in developing countries, so are the potential costs. Most developing countries lack the scientific capacity to assess the safety of GMOs, the economic expertise to evaluate their worth, the regulatory capacity to implement guidelines for safe deployment, and the legal systems to enforce sanctions and punish transgressions of the law. Since developing countries contain the centers of origin of many of the world's leading food crops, any negative impacts on wild flora and fauna could have repercussions for global biodiversity.

Recognizing that the stakes are unusually high in developing countries, a number of organizations are working to build local capacity to manage the acquisition, deployment, and monitoring of GMOs. The international research centers that are members of the Consultative Group on International Agricultural Research (CGIAR) have recently stepped up efforts in this area. Convinced that decisions concerning the production and use of GMOs must be left to national governments, the centers believe that policy makers must be able to make well-informed choices based on a thorough understanding of the technical, economic, and political issues. Many of the centers therefore are working to train researchers from developing countries in genetic engineering techniques, facilitate access to proprietary technologies available mainly in the North, and encourage the implementation of effective systems for objectively evaluating GMOs.

10. What are the long-term prospects for GMOs?

Considering the tumultuous history of the debate over GMOs, it would be foolish to try to predict the outcome. Yet despite all the current uncertainty, several points seem clear.

First, as a technology for creating economically valuable crop varieties, genetic engineering is simply too valuable to ignore. Given recent advances in biotechnology, the process by which humans breed better crop varieties has changed forever. Although it will not always be possible to identify individual genes of interest and move them around at will using genetic engineering techniques, in those cases in which economically valuable genes can be identified and manipulated, it will often be very inefficient to rely on conventional plant breeding methods. Using conventional methods, scientists must cross large numbers of individual parent plants to create random recombinations of genes and then painstakingly select out the superior progeny.

Second, the possibility of making inter-specific gene transfers opens the door to creating organisms that differ in important respects from naturally occurring organisms. Whether the differences are differences in kind or merely in degree is finally a matter of opinion, but in a sense the point is immaterial. As with any new product, the impacts of GMOs on people, on animals, and on the environment are difficult to predict, so it is important that the potential risks be evaluated before GMOs are approved for release. The evaluation process inevitably will have to include carefully controlled field testing, since only field testing will generate the information needed to determine how GMOs will perform in the hands of farmers.

Third, given the importance people place on the food they eat, policies regarding GMOs will have to be based on an open and honest debate involving a wide cross-section of society. In hindsight, it is clear that the agri-biotech industry miscalculated in arguing that genetically modified foods are no different from other foods and therefore need not be subject to special treatment or even distinguished in the marketplace. This attitude merely served to heighten suspicions among some consumers that the industry is seeking to increase profits by promoting a technology that has few obvious benefits and may in fact pose hidden dangers. In order to achieve the consensus needed to move forward, all parties in the debate will have to recognize the validity of others' concerns and take steps to resolve unanswered questions. In this context, the experience of Switzerland is instructive. In Switzerland, widespread concerns about the safety of GMOs led to a campaign by scientists in the public sector, supported by the biotechnology industry, to educate the public about the scientific aspects of biotechnology; in a subsequent national referendum, once-skeptical Swiss voters endorsed biotechnology.

Finally, decisions about the future of GMOs should be based on scientifically validated information, not unsubstantiated claims, half-truths, or simple emotion. One big problem with the current debate is that the opposing parties use information selectively, at times glossing over gaps in the knowledge base and frequently bolstering their arguments with misinformation. In promoting GMOs, the agri-biotech industry has on occasion been guilty of overstating potential benefits and downplaying potential risks. Opponents of GMOs have done the opposite, dismissing potential benefits and exaggerating potential risks. If the controversy is to be resolved, the politically motivated rhetoric must give way to serious discussion based on credible, science-based information. The stakes are too high to waste more time on useless posturing.

Further reading

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