# GMOs – Food Supply Saviour or the Devil in Disguise?

Margaret E. Smith

Plant Breeding and Genetics, G42 Emerson Hall, Cornell University, Ithaca, NY, 14853
Email: mes25@cornell.edu

## Take Home Messages

- Genetically engineered (GE) crop varieties (or GMOs) result from a new tool that humans are using to genetically improve crops. Human intervention in crop genetics through selection and conventional breeding goes back thousands of years.
- Currently, there are commercially-sold GE varieties of soybean, corn (both field corn and sweet corn), cotton, canola, sugar beet, alfalfa, papaya, and summer squash (both green and yellow). GE potato and apple were approved in the U.S. recently, but there are no commercial plantings of these GE crops yet.
- Adoption of GE herbicide tolerant crop varieties in the U.S. has led to increased herbicide use per acre. However, it has also led to more use of an herbicide with low environmental impact quotient and reduced use of more damaging herbicides, and it has facilitated reduced tillage.
- Adoption of GE insect resistant varieties of cotton and corn in the U.S. has led to reduced insecticide use per acre.
- Four multinational companies own about 75% of the U.S. approvals for commercialization of GE crop varieties.
- Ingredients derived from GE crop varieties are found in an estimated 60-70% of packaged, processed foods in the U.S.
    - Most are present as highly refined ingredients that no longer contain any of the GE genetic material or its protein product.
    - Highly refined ingredients from a GE variety and from a non-GE variety are chemically indistinguishable.
- There is no credible evidence of food or feed safety concerns with currently-commercialized GE crop varieties.

## Introduction

Genetically engineered (GE) organisms (what many call GMOs – genetically modified organisms) are increasingly showing up in newspaper headlines and on web sites, blogs, and emails. There have been media splashes about new genetically engineered crop types, proposed labeling legislation, and even shocking photos claiming to show animals harmed by consuming GE crop products. After noting why it may be that genetic engineering has stirred up so much controversy, this article will describe GE crops, their prevalence, and evidence about the impacts of GE crop adoption. The aim is not to tell anybody what they should think about GE technology, but rather to help explain what is known about GE crops and thus help all of us arrive at better-informed personal perspectives on GE crops and their roles in our agricultural and food systems.

## Why the Controversy?

It is not often that plant breeding-related topics make it to newspaper covers, or are the subject of activists' protests. Why now? Shortly after the first GE crops were commercialized in 1996, Hallman et al. (2001) did a survey of the general public to assess their understanding of traditional crop breeding and genetic engineering (which was newly entering the market at that time). After a simple explanation of traditional cross breeding, respondents were asked, "Have you ever eaten a fruit or vegetable created using these methods?" Only 28% correctly answered "yes", while 61% said "no" and 11% were not sure (Figure 1, stippled bars). In reality, North Americans have eaten little but traditionally cross-bred crops for at least the last hundred years. Responses were very similar when people were asked a question about whether they had ever eaten a GE fruit or vegetable (Figure 1, solid bars), even though almost none were available in the market at the time.

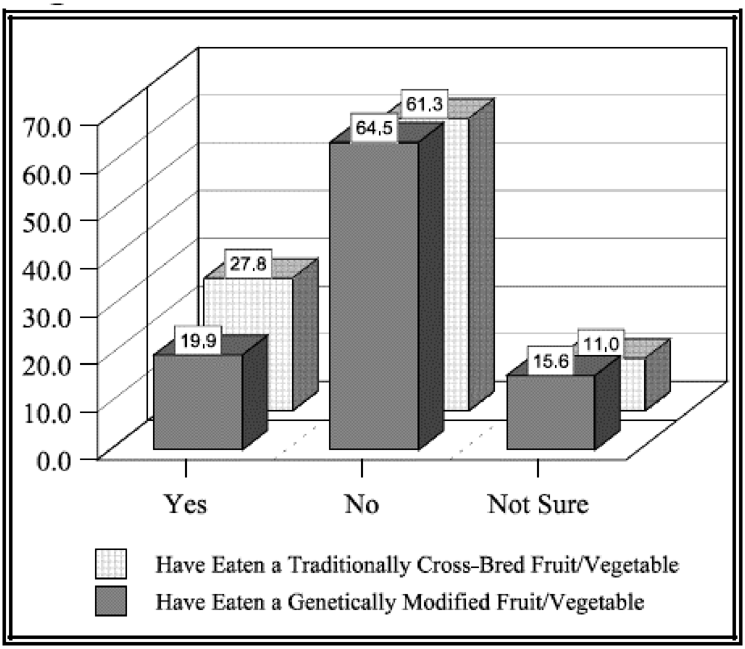



**Figure 1. Reported consumption of traditionally crossbred and "genetically modified" (GE) fruits and vegetables. Source: Hallman et al., 2001.**

Clearly, the general public has limited understanding of past or present human efforts at crop breeding. Along with that confusion, we have introduced a new genetic technique that is being applied to ingredients in the food we eat every day. Mix that with the perception that any new technology probably brings with it some inherent risks, and it is no surprise that controversy resulted.

## ▪ What are Genetically Engineered Crop Varieties

### Genetics of Crop Domestication and Improvement

GE crops cannot be fully understood without first considering the history of our domesticated crops. Virtually all of them had their origins thousands of years ago, with wild species that early hunter-gatherers found to be useful as sources of food. For corn, that wild ancestor was teosinte – a grass with heads containing about ten small seeds that fell on the ground when they were mature and were indigestible unless they were cracked or ground to break open the seed coat (Figure 2). As for all living organisms, the traits of wild crop ancestors were determined by the genetic code contained in their DNA. That code provides the instructions for how any organism appears and how it grows. The DNA code varies from plant to plant of the same species, allowing for individuals to differ one from another. Since the entire DNA code must be copied every time a cell divides (to provide copies for the two daughter cells), copying mistakes (called mutations) happen regularly. These mistakes, or mutations, are the source of differences among individuals of the same species.

**Figure 2. Modern corn (left) and its wild ancestor, teosinte (right).**

As the early gatherers found naturally occurring mutant types that happened to be useful to them, they collected and saved them. For example, they would have chosen and saved seed from teosinte plants that had larger seeds, and seeds that stuck to the central stem (now the cob) when they were mature rather than falling on the ground, and seeds lacking the hard indigestible seed coat. Gradually, those genetic changes (resulting from natural mutations) combined with farmers' selection of seeds from the most useful and productive plants created a new domesticated crop, corn, from what had been a wild plant. Similarly profound changes took place in all our domesticated species – a long-term process of genetic modification brought about by human selection. Since the time of domestication, human breeding and selection of crops and livestock has continued and intensified as our knowledge of genetics and performance measurement has improved. In reality, our domesticated crops are no longer "natural." Most would never survive in nature (that is, without a partnership with farmers who cultivate them) because they have been so profoundly genetically changed from their wild ancestors and even from their earlier domesticated predecessors (Figure 3).

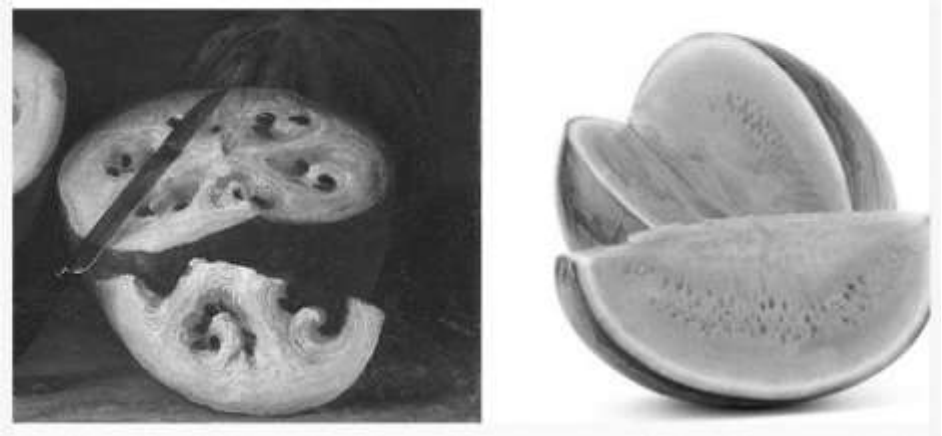


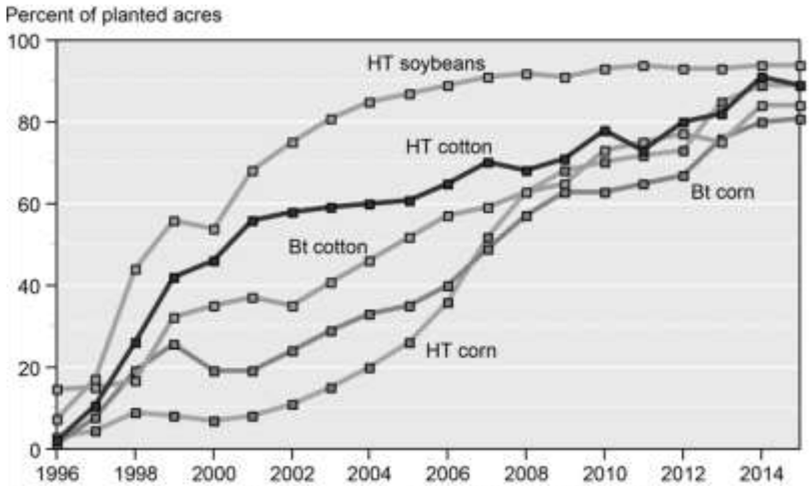
**Figure 3. Watermelon from a still life painting done in the 1600s (left) and current day watermelon improved by traditional plant breeding (right). Photo credit: Christie Images LTD.**

## Genetic Engineering – A New Tool for Crop Genetic Improvement

Although it is being applied to crops that resulted from this lengthy background of genetic improvement, genetic engineering is, indeed, a new tool that changes the genetic code in ways that were not previously possible. Our increased scientific understanding of the genes that control inheritance has allowed us to identify the genetic material of an organism that enables it to make particular compounds. For example, the bacterium *Bacillus thuringiensis*, long sold as a natural, organic, bacterial insecticide, can infect and kill certain caterpillar- and beetle-type insects. Researchers identified the gene in this bacterium responsible for producing a protein that becomes a toxin inside a caterpillar's or a beetle's alkaline gut. They then cut this gene (called the Bt gene) from the bacterial genetic material and inserted it into crops like corn and cotton to create insect resistant versions of these plants: so-called Bt corn and Bt cotton. For each insect, a slightly different variant of the Bt gene from the bacterium is used because those genes differ in how effective they are against different insect species. In corn, for example, there are several different Bt-corn borer genes that also all differ slightly from the Bt-corn rootworm genes. Several of these genes are built into many commercially-available GE corn varieties.

A similar process was used to create GE plants that are able to tolerate being sprayed with herbicides that are normally toxic to plants. These include the glyphosate (Roundup) resistance genes and the glufosinate (Liberty) resistance gene, both originally found in naturally-occurring soil bacteria. Herbicide resistance from these genes (especially the "Roundup Ready" glyphosate resistance trait) has been built into many GE crops, including soybean, corn, cotton, canola, alfalfa, and sugar beet.

Genetically engineered insect resistant (Bt) and herbicide tolerant (HT) crop varieties (including many with both traits together) are planted on the majority of U.S. soybean, field corn, and cotton acres (Figure 4). Although USDA does not track data on other crops, GE canola, sugar beet, and papaya varieties are reported to occupy the majority of acreage for these crops as well. Clearly these GE varieties have been widely adopted by farmers.




Data for each crop category include varieties with both HT and Bt (stacked) traits.
Sources: USDA, Economic Research Service using data from Fernandez-Cornejo and McBride (2002) for the years 1996-99 and USDA, National Agricultural Statistics Service, *June Agricultural Survey* for the years 2000-15.

**Figure 4. Adoption of GE crops in the U.S. 1996-2015. HT = herbicide tolerant. Bt = insect resistant. Source: USDA ERS, 2015.**

## Similarities and Differences: GE vs. Traditional Plant Breeding

So how does genetic engineering differ from "traditional" plant breeding? ("Traditional" plant breeding means the kind of selection and breeding practiced by early farmers and by plant breeders for over 100 years – cross pollinating different parents and searching among the offspring to find genetically superior types.) The GE crop varieties in the marketplace now were created by moving individual genes between organisms that cannot naturally cross breed with each other (like a soybean and a bacterium). For many years, plant breeders have made crosses between crops and their wild and weedy relatives to transfer genes for traits like pest resistance to the domesticated crops, so this process is not entirely new. However, traditional plant breeders are limited to moving genes between organisms that are so closely related to each other that they can be sexually crossed. So the range of genes that can be introduced into a GE variety is broader than what traditional plant breeding has access to, because genetic engineers can reach beyond the boundary of sexual cross-compatibility. Second, when making sexual crosses, the offspring receive a relatively random mix of the genes from both of their parents, including both desired genes and any others that come along with them. Genetic engineering, on the other hand, inserts only one or a few genes into an existing crop variety, so the GE variety differs by only one or a few genes from its parent. This is why genetic engineering is described by some as more precise than traditional cross breeding. Lastly, the ability to identify and manipulate individual genes has led to the legal right to patent genes, so most (if not all) GE traits are patented and their use is legally constrained by the patent holder.

There are also similarities between traditional plant breeding and genetic engineering. Both depend on changes in the genetic code to create crops that are agriculturally superior. Both approaches aim to modify crops to better meet human needs, just as the earliest farmers who domesticated our crops did. Finally, it is not new that private companies seek a return on their investments in plant breeding. With traditional plant breeding, they were able to do that through plant variety protection laws and through marketing hybrid varieties for which seed must be bought each year. With genetic engineering, the option of patenting genes has provided a different avenue for private companies to seek a return on their investment. Thus, although genetic engineering is a distinct new tool for plant breeding, it shares some fundamental elements with traditional plant breeding: genetic variation is the basis, improving crops to better meet human needs is the goal, and private companies all seek a return on their research investment, whatever the nature of that research.

## ▪ Issues and Concerns Regarding GE Crops

The issues and concerns being raised regarding GE crops include some that can be informed by science (e.g., economics of production and use, environmental risks, food and feed safety) and others that are societal value questions (e.g., should GE crop products be labeled in the market?; is there too much concentration in the industry that controls and profits from GE traits?; is genetic engineering ethically wrong?). This section will cover the primary areas of concern about GE crops and describe data and research results that shed light on these concerns.

### Economic Costs and Benefits

From a farmers' point of view, the farm-level economics of growing a GE vs. a non-GE variety is of paramount concern. The U.S. National Academy of Sciences' National Research Council summarized the peer-reviewed scientific studies that quantified farm-level impact of adopting GE crop varieties in the U.S. (NAS NRC, 2010). The authors found that many farmers had benefited economically from adopting GE crop varieties. Seed of GE varieties is typically more costly because of the “technology fees” for the GE traits, and it is sold with technology use agreements that prohibit saving seed (even for your own on-farm use). There are also some domestic and international markets with limited acceptance of GE varieties. All of these factors can make production costs higher for a GE variety. On the positive side, however, GE varieties may achieve better yields, reduce labor and production costs, allow greater flexibility in management, and provide increased convenience for producers. In the future, there may be GE crops whose products have value-added benefits for consumers or processors and thus they will receive price premiums, but these types of varieties are a tiny fraction of the commercial GE crop market at present. What should be clear from this brief list is that economic costs and benefits are very case specific, depending on the individual farm operation, the GE crop and trait being considered, and the marketing environment.

## Environmental Impacts

Both farmers and consumers wonder about environmental impacts of GE crops. The NAS NRC (2010) study found that adoption of GE varieties resulted in positive environmental impacts from reduced insecticide use and from less need for tillage (resulting in reduced erosion potential). There has been a pronounced reduction in insecticide use in field corn and cotton with increased adoption of Bt corn varieties (Figure 5).

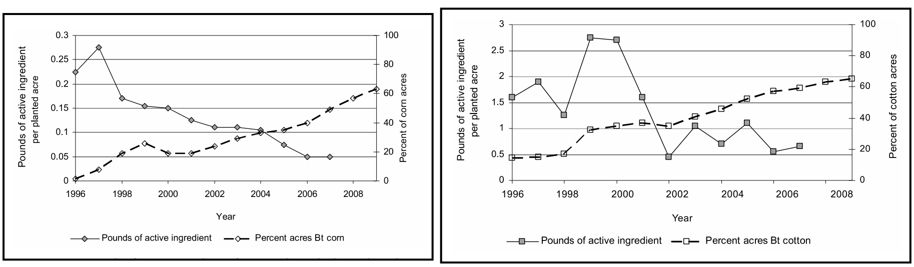



**Figure 5. Insecticide use (solid line) and adoption of Bt varieties (dashed line) in the U.S., 1996-2007, for field corn (left) and cotton (right). Source: NAS-NRC, 2010.**

The results regarding herbicide use were less clear; overall herbicide use increased with adoption of GE crop varieties, but there was more use of an herbicide generally considered to be less toxic (glyphosate) and reduced use of some of the more environmentally undesirable herbicides. Figure 6 shows herbicide data for cotton, where the increase in total herbicide use can be most easily seen, and for soybean, where the shift in types of herbicides used is most pronounced. This combination of changes makes debate regarding herbicide use particularly complicated; opponents of GE crops can point to data showing that increased GE crop adoption has resulted in increased herbicide use, and advocates of GE crops can point to data showing that use of environmentally-undesirable herbicides has declined and reduced tillage (with its environmental benefits) has been promoted. Both points are correct, but neither provides the full picture.

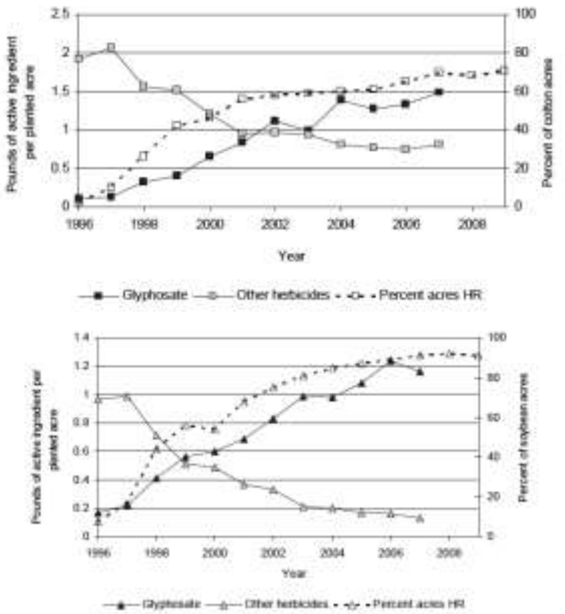



**Figure 6. Herbicide use on cotton (left) and soybean (right) in the U.S. from 1996 to 2007. Solid black line: glyphosate use, solid gray line: other herbicide use, dashed line: percentage of U.S. acres planted to GE herbicide tolerant varieties. NOTE: The strong correlation between increased acreage of herbicide tolerant varieties and changes in herbicide use suggests, but does not confirm, causation between these variables. Source: NAS NRC, 2010.**

The NAS NRC (2010) study noted the risk from pest evolution to overcome GE resistance. This is a risk for any pest control method, including traditionally bred resistance, chemical pesticides, and even some cultural control methods. Evolution of pest resistance to a control measure happens most readily when a single control approach is used repeatedly and over a large acreage. That is exactly what is happening with glyphosate resistant crops, and farmers are now seeing weeds that are resistant to glyphosate (Boerboom and Owen, 2006). There is evidence of the same problem with corn carrying the Bt-corn rootworm trait, and a few well-documented examples of control failures have occurred in recent years (Tabashnik et al., 2013). Both GE crop types have been very popular and provided very good pest control. Their effectiveness may have led farmers and the seed industry to rely too heavily on these single control measures. As with any pest control measure, over-use favors pest evolution towards more resistance. The importance of rotating or alternating pest control methods is a principle we learned long ago and have promoted through integrated pest management programs. It seems we need to re-learn it with respect to GE pest resistance tools!

## Safety as Food and Feed

From a consumer's point of view, the logical concerns are whether GE crop varieties are found in foods, whether they are safe as food and feed, and whether GE approaches have or could introduce allergens into common foods.

A body of over 200 independently-funded studies has not revealed evidence of any food or feed safety concerns with currently commercialized GE crop varieties (Haro von Mogel and Bodnar, 2015; NIcolia et al., 2013). Those few studies that have purported to show problems from feeding GE crops to animals have been widely discredited by scientists for their poor design, inappropriate analysis, and other scientific problems. There are also many peer-reviewed, published studies conducted by the private sector that show no evidence of food or feed safety concerns. Some people regard these studies as open to question, since most were carried out by the same companies that have a vested interest in marketing GE crop seed. That is true, but two points should be taken into account. First, many of these studies have had to meet the standards of scientific scrutiny that the peer-reviewed publication process demands, which provides some assurance (though not a guarantee) of scientific integrity. Secondly, it is not clear what mechanism exists to fund extensive safety testing done by the public sector (on the contrary, public funding for research has long been on the decline). In the absence of increased public sector funding, testing will continue to be done largely by those who can hope to recoup their research investment – the private sector companies who hope to market GE seed.

Concern about novel and unanticipated allergens is also important for consumers, as there is the chance that genes from organisms we don't normally consume as food might have allergenic potential. Testing for allergens has relied on scientific understanding of the general nature of allergenic compounds, and on evaluating how fast the new proteins produced by GE varieties break down by human digestive enzymes. New gene products that are anything like known allergens are extensively tested. Any new protein that breaks down more slowly than others when exposed to digestive enzymes is extensively tested (the longer something stays in your gastrointestinal tract without breaking down, the more time it has to cause an allergic reaction). Although this approach to monitoring for allergens has not proven very reassuring to concerned consumers, it is not clear that a better approach exists.

## Labeling of GE-derived Food Products

There are other areas of concern about GE crops that are not scientific in nature. These concerns include the debate about labeling GE-derived foods, concerns revolving around consolidation of seed industries and profits from GE crops, and opposition to genetic engineering that is ethically or religiously based. As noted at the beginning of this section, there is a limited contribution that science can make to these debates. However, the following paragraphs provide some data in which to ground discussions of these concerns.

At present, there is extensive political and media debate about whether foods derived from GE crop varieties should be labeled. Various groups have estimated that 60% to 70% of packaged foods in a typical North American grocery store contain one or more ingredients from a GE crop variety. This level is not too surprising given the prevalence of ingredients derived from corn, soybean, canola, and even cotton in our processed foods, and the fact that the vast majority of North American acreage of these crops is planted to GE varieties.

Most food labeling in the U.S. and Canada is product based; it tells something about the content of the food in the package (how much protein, fat, oil, fiber, vitamins, etc. is in a serving). Many of the corn, soybean, canola, and cotton derivatives found in processed food are highly refined ingredients, like corn starch, oils, corn syrup, soy lecithin, and many more. These ingredients are purified and do not contain DNA or proteins. In such highly refined ingredients, there will be no detectable difference between a version derived from a GE variety and a version of that same ingredient derived from a non-GE variety. For example, corn syrup is chemically just sugars and water, so corn syrup from a GE corn and corn syrup from a non-GE corn will be chemically indistinguishable. This complicates labeling, because packaged foods that contain these highly refined ingredients from GE varieties would show no measurable difference from those made with ingredients from non-GE varieties, raising the question of what the label tells us and the complication that there is no means for verifying the label accuracy by testing the product on the shelf.

A consumer survey that asked “Should GM food be required to be labeled?” found that 73% of respondents said “yes” (Hallman et al., 2013). That same survey asked “What information would you like to see on food labels that is not already there?" and only 7% of respondents brought up GE crop content. As always, the answer you get regarding the importance of labeling depends on how you ask the question. Proponents and opponents of labeling will use different parts of this same study to make their case – clearly an over-simplification of what the data tells us. There is no doubt that labeling will imply a cost, primarily due to keeping GE and non-GE crops and their products segregated from planting all the way to the grocery store shelf, and tracking them to ensure label accuracy. It is not clear that labeling will increase consumer choice, since there are already non-GE options available in stores including both certified organic products, which cannot be produced with varieties that were genetically engineered, and products voluntarily labeled as "Non-GMO Verified" (Non-GMO Project, 2015).

## Industry Consolidation and GE Crop Varieties

There is some concern that GE crops contribute to the overall trend toward consolidation, globalization, and industrialization in agriculture. The ability to patent genes appears to vest control over the raw material of agriculture – the genetics of our crops and livestock – in large private sector corporations. Developing and bringing a GE crop variety to market is a costly prospect, so it is beyond the reach of many smaller seed and crop breeding enterprises. Recovering the research and development investment for GE varieties has led some seed companies to seek as many outlets for their varieties as possible, adding additional push to what was an on-going trend toward consolidation in the seed industry. This can be seen by examining which companies have received approvals to commercialize GE varieties, and who now owns those companies. Of the 117 approvals for GE variety commercialization that have been granted in the U.S. to date, the original applicants included 31 different entities (private companies, universities, government agencies; Figure 7, top). With industry consolidation that has taken place since approvals were granted, these now represent only 19 independent entities, and 88 of the 117 GE variety approvals are held by only four companies (Figure 7, bottom). If the planned merger between Dupont and Dow moves forward, four companies will hold 98 of the 117 GE crop approvals. Whether this degree of concentration in ownership of GE crop technology is cause for concern is a societal value judgment, not a question that can be answered by scientific research.

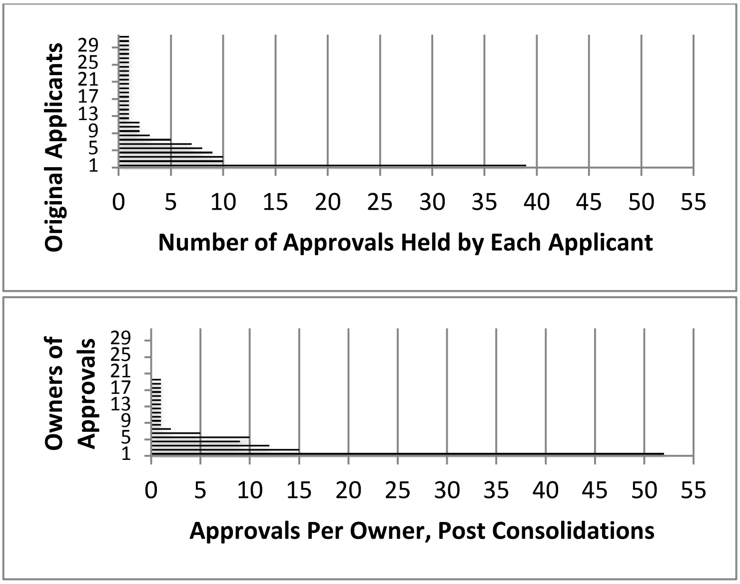



**Figure 7. Original applicants for approvals to commercialize GE crop varieties (top) and owners of approvals after seed industry consolidation (bottom). Data source: ISB, 2015.**

## Ethical and Other Concerns

Some oppose GE technology based on ethical or religious beliefs. These too are concerns that cannot be answered by scientific studies. They will have to be addressed through public and political debate, policy-making, and regulation, which are the approaches we use to implement societal value judgments.

# ▪ Summary

So what's the bottom line? GE crop varieties have their basis in genetic variation and creating new genetic combinations – phenomena that we have used for centuries to improve our crops for human use. However, GE is a new and different tool for crop improvement. The resulting varieties need to be monitored for their effectiveness, safety, and environmental impacts just like any other new technology. The outcomes of such evaluations will vary depending on the particular crop and trait, so evaluations must be made on a case-by-case basis. The currently commercialized GE varieties, which are primarily (but not exclusively) corn, soybean, cotton, canola, sugar beet, and papaya varieties, have proven themselves attractive to farmers and have not revealed any negative effects as food/feed. They have reminded us of what we should have learned well a long time ago – it is unwise to repeatedly use the same pest control methods over large areas, because the pests tend to evolve to overcome those control methods. So we all need to remember that GE varieties, just like any other technology, are not a silver bullet for pest control. They must be used wisely. Finally, a robust body of scientific study has addressed questions of food and feed safety, and no convincing scientific evidence of problems with currently commercialized GE varieties has been revealed to date. On-going evaluation and monitoring will be needed to ensure the continued safety of GE varieties and their products in the future.

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