Our researchers explain what science reveals about GMOs—both the benefits and the risks.

By Sara LaJeunesse
INTERVIEWER:
What is a GMO?

YOUNG WOMAN:
I know it’s bad, but to be completely honest with you, I have no idea.

In October 2014, talk show host Jimmy Kimmel took to the streets of Los Angeles to find out what people knew about genetically modified organisms (GMOs).

Of course, Kimmel elected to air mostly conversations with people who had no clue about GMOs, likely to the exclusion of those people who did. But the fact remains that many Americans have little understanding about GMOs, yet they feel passionately about the topic, often believing that GMOs are unsafe. To be precise, only 37 percent of the American public believes that GM foods are safe to eat, while 88 percent of scientists believe they are safe, according to a survey conducted in 2014 by the Pew Research Center (1).

Indeed, there is a vast rift between scientific evidence for the benefits and risks of GMOs and the public’s perception of the benefits and risks of GMOs. Yet science is the only systematic and replicable tool that humankind has for understanding the world around us. Whether GMOs fit within an individual’s value system or not, they are part of our world, and their impacts on human health and the environment—at least those impacts we choose to investigate—can be understood through rigorous science.

So what exactly does science reveal about GMOs? Well, first let’s talk about what GMOs are.

What Are GMOs?

All organisms change over time—that’s evolution. But some 10,000 years ago, humans figured out they could speed up and direct the process of evolution by selecting individual organisms that exhibited preferable traits and crossing, or selectively breeding, them with each other. Prehistoric humans did this with maize, over time turning the grassy weed, teosinte, which had scruffy clusters of seeds, into a crop that produced plump, nutritious kernels. They also did this with our first pets, dogs, transforming them from their wild wolf ancestors into the incredibly diverse assortment of domesticated canines we know and love today.

To achieve outcomes that once took thousands of years and countless failures, scientists now are turning to genetic engineering techniques, which enable them to speed up the process of evolution and fine-tune it to create precise changes in the physical attributes of organisms to achieve certain benefits.

This type of rapid genetic manipulation began in 1973 when the first “GMO”—an E. coli bacterium carrying a gene from another species of bacterium that enabled it to become resistant to the antibiotic tetracycline—was created. Later, in 1982, Humulin—a form of human insulin produced by genetically modified bacteria—was approved by the U.S. Food and Drug Administration. In 1992, the first GM plant—the Flavr Savr tomato, engineered to remain firm longer to allow for vine ripening—was approved for commercial production in the United States. Monsanto’s Roundup Ready soybean was given the go-ahead by the U.S. Department of Agriculture in 1994, followed in 1997 by the approval of insect-resistant Bt cotton. In 2009, the FDA approved the first GM animal, a goat that produces an anticlotting agent in its milk that can treat people with clotting diseases. Finally, the Arctic Apple, which is genetically engineered to resist browning, was approved by the USDA in February 2015 and by the FDA in March 2015.

Other GM crops approved for sale in the United States today
include potatoes, sugar beets, rapeseed/canola, corn, soy, and cotton. In addition, several varieties of genetically modified crops in the late stage of testing include crops that are salt tolerant, crops that produce omega-3 fatty acids, canola that requires half the amount of nitrogen fertilizer, pink pineapples that contain cancer-fighting lycopene, and wheat with reduced potential to cause allergies. GM animals that are being investigated include salmon that grow to market size faster, chickens that are resistant to avian influenza, and pigs that utilize phosphorus more efficiently and pollute less.

How are all these organisms created? The simplest method includes using natural enzymes to cut a gene—or fragment of DNA—from one organism and insert it into another organism either indirectly via some kind of vector, such as a virus, or directly via a gene gun or microinjection technique, for example. Generally, the introduced gene confers a new trait to the organism.

Newer techniques for creating GMOs allow scientists to more precisely change the sequence of genes to introduce the desired trait. Known as “genome editing,” the techniques involve removing, inserting, or editing a fragment of DNA using bacterial enzymes that are like “molecular scissors.” These enzymes are part of the immune systems of microbes, which use them to edit their own genomes and protect themselves from attack by pathogens.

As it turns out, bacteria and viruses have been doing this “gene swapping” for millennia. Once scientists saw how the microbes did it, it was not long before they developed tools to move genes around in plants and animals themselves. “We now have the ability to edit genes like you would edit a document in your word processor,” said Troy Ott, professor of animal science. “It’s like taking the book War and Peace, turning to page 743, and changing the word ‘man’ to the word ‘woman.’”

To create the most widely used GMOs—Roundup Ready crops, which are engineered to be resistant to glyphosate (the active ingredient in Roundup)—scientists at Monsanto investigated an enzyme in plants called EPSPS. The enzyme is part of a pathway that manufactures three of the 21 amino acids—the building blocks of proteins—that all living things have. Glyphosate binds EPSPS, preventing it from producing these three amino acids.

“The plant gradually starves to death,” said Richard Roush, dean of the College of Agricultural Sciences.

To avoid this outcome for crop plants, the Monsanto scientists found a form of EPSPS in bacteria that is naturally resistant to glyphosate and used it to engineer crop plants that also were resistant. Now, when glyphosate is applied to the crops only the susceptible weeds die.

**Regulating GMOs**

Since the introduction of GM crops in 1996, farmers have adopted the technologies widely. In 2014, around the globe, nearly 500 million acres of biotech crops were grown in 28 countries (2). That’s at least 15 million acres more than were grown in 2013.

“The adoption trajectory of these technologies has been unprecedented,” said David Mortensen, professor of weed and applied plant ecology. “The very first of the
herbicide-resistant GMOs [soybeans] became available in 1996, and by 2006 or so we were upwards of 90 percent adoption in the United States. It is phenomenal for anything to be adopted at that rate and that completely."

Most of the harvest from these crops are fed not to humans as one might expect, but to livestock. In the United States, more than 9 billion food-producing animals are raised each year annually, and more than 95 percent of these animals have been consuming feed containing GM ingredients for almost 20 years (3).

With such a rapid adoption rate, and with so much of the food going to animals instead of humans, how are GMOs regulated?

According to the Library of Congress, GMOs are regulated under the same U.S. laws that govern the health, safety, and environmental impacts of conventional foods (4); there are no special regulations that govern GMOs. However, the government has taken the position that it will evaluate the risks and benefits of each new GMO individually through conventional processes. Regulatory agencies employ a concept known as “substantial equivalence,” which the Food and Agriculture Organization of the United Nations defines as “the concept that if a new food or food component is found to be substantially equivalent to an existing food or food component, it can be treated in the same manner with respect to safety (4).” Depending on the type of GM food, evaluation may fall under regulatory oversight of the FDA, USDA, EPA, or all three. “This is a science–based approach,” said Ott. “It’s the safest way to do it.”

Human Health

Ask just about any scientist if GMOs are bad for our health and he or she will say, “Probably not.” That’s because no reputable studies have shown any negative health effects of eating GMOs, at least so far. And scientists around the world continue to look for any evidence of risk or unintended consequences.

“Europe is famous for being the place with the greatest objection to GM crops, so I think it’s instructive that the European Union spent nearly $300 million to study the impacts of GMOs, and what they concluded was that essentially there is no substantial difference between GM and non-GM crops in terms of either food safety or environmental impact,” said Roush.

Indeed, the EU report, published in 2010, stated, “The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se more risky than e.g. conventional plant breeding technologies (5).”

A separate review of the scientific literature published in 2014 examined animal health in particular. The review examined data on over 100 billion animals following the introduction of GM foods and found no “unfavorable or perturbed trends in livestock health and productivity (3).” In fact, during the period studied, animal health and growth efficiency actually improved.

Ott noted that some of the concern about the health effects of GMOs may be due to a study—which was flawed and later retracted—claiming that feeding GM corn to mice caused them to develop tumors. However, he said, much of the concern is generated from claims of risks found ubiquitously on the Internet and social media posted by individuals opposing the use of the technology or by people selling non-GM foods.

Beyond actually ingesting GM foods, some people worry that the genes inserted into GMOs could “jump” out of target plants or animals and into other organisms. Indeed, “horizontal gene transfer”—the transfer of genetic material from one organism to another without reproduction or human intervention—is a real phenomenon, one that has occurred in nature since the beginning of life on Earth. For example, scientists have known for some time that natural insertion of genetic material from viruses into the human genome is responsible for a significant proportion of cancers (6). Yet, a review article published in 2008 noted that the risk of horizontal gene transfer from GM plants to human health or the environment is negligible (7).

When it comes to the health risks of GMOs themselves, Mortensen believes there is science yet to be done that could reveal more compelling evidence of health effects. “When we do science, if we do it well, it is objective, but the science that we choose to do is subjective,” he said, suggesting that perhaps the right questions have not yet been asked. But data do exist indicating that the herbicides used on GM crops may have negative health effects. “GM seeds do not exist in isolation, but rather
In 2014, 28 countries worldwide produced a total of 181.5 million hectares of biotech crops.

Source for infographics: ISAAA Global Status of Commercialized Biotech/GM Crops in 2014. Pocket K No. 16
To achieve outcomes that once took thousands of years and countless failures, scientists now are turning to genetic engineering techniques. The map on the left depicts the relative distribution of biotech crops planted in industrial and developing counties. In 2014, 18 million farmers (nearly 17 million of whom were small and resource poor from developing nations), planted biotech crops.

Total global production of biotech crops in hectares in 1996 compared to 2014. Over the past 18 years, biotech crops have been successfully grown in 1.78 billion hectares.

Global production of biotech crops in hectares in developing nations compared to industrial nations in 2013.
are sold alongside pesticides, which they are designed to resist,” said Mortensen. “Using a technology that results in a clear and deliberate intended increase in the use of pesticides, some of which have negative health effects associated with them, and very clear ones, well there are clear health downsides to that.”

Glyphosate is the most commonly used herbicide and is applied to Roundup Ready crops, including soy, corn, canola, alfalfa, cotton, and sorghum. Most people agree that the health effects of glyphosate are not as severe as some of the other pesticides in use. However, there is not universal agreement on this issue. “The health effects of exposure to glyphosate are not clear,” said Mortensen, “but I don’t think there is compelling data to indicate that the herbicide is dangerous.”

Roush too believes that glyphosate is “arguably the safest herbicide ever developed. It is so safe that we let people buy it in grocery stores and take it home and spray it in their gardens,” he said. “Its toxicity is on the order of salt.”

But Roush and Mortensen are less enthusiastic about some of the other pesticides in use. Mortensen, in particular, is concerned about the use of an herbicide known as 2,4-D (2,4-Dichlorophenoxyacetic acid), a widely used chemical that will soon become even more widespread in its use. He predicts its use will increase four- to sevenfold (8). Resistance to the herbicide 2,4-D—along with glyphosate resistance—is a feature in a new, stacked (containing two or more GM traits) plant developed by Dow AgriSciences as part of the Enlist Weed Control System, which was approved by the U.S. Environmental Protection Agency in October 2014. According to the EPA’s website, “When used according to label directions, Enlist Duo is safe for everyone, including infants, the developing fetus, the elderly, and more highly exposed groups as agricultural workers (9).” So far, the EPA has approved the use of Enlist Duo, an herbicide containing glyphosate and 2,4-D, for six years in six states: Wisconsin, Ohio, South Dakota, Indiana, Iowa, and Illinois.

The EPA’s statement, however, is in direct opposition to some recent research findings. For example, a meta-analysis of some 45 studies from around the world found that 2,4-D is strongly correlated with an increase in non-Hodgkin’s lymphoma and with a number of neurological disorders, including early onset dementia and Alzheimer’s disease (10).

According to Roush, one of the most important things that Roundup-resistant crops have done around the world is to replace many herbicides of dubious safety with one (Roundup) that is safer. So why the need for Enlist Duo crops? Why add 2,4-D to the mix?

The Environment

According to Mortensen, the answer is weed resistance. “About 40 percent of the corn and soybean fields across the United States and at least that percentage of cotton fields across the south have glyphosate-resistant weeds in them,” he said. “It happened so quickly.”

As do all organisms, weedy plants naturally contain a significant amount of genetic variation. So the possibility always exists that a small number of weeds will exhibit a genetic makeup that allows them to survive a particular herbicide application. When they do, these survivors are free to grow and reproduce. Over time, the population of resistant weeds increases.

Mortensen said that weed resistance to Roundup has occurred because farmers have overused the pesticide. In fact, resistance to Roundup predated Roundup Ready crops, but the new technology has accelerated development of glyphosate-resistant weeds. “Farmers have planted the same transformed crop year after year in the same fields with the same herbicide applications,” he said, “and now we have widespread resistance.”

Mortensen worries that adding 2,4-D resistance to crops on top of glyphosate is a step on a “pesticide treadmill” in which more and more pesticides—and possibly more dangerous pesticides—will be needed to stay ahead of weed resistance.

Besides resistance, another danger of applying herbicides is drift. In his 2012 BioScience paper, Mortensen wrote: “All herbicides can have negative impacts on non-target vegetation [including plants that are important for pollinators] if they drift from the intended areas either as wind-dispersed particles or as vapors evaporating off of the application surface. Because of their volatility and effects at low doses, past experience with injury to susceptible crops has indicated that the synthetic auxin herbicides [including Enlist Duo] may be especially prone to drift problems and many crop plants are very sensitive to this class of herbicides (8).”

GMOs are regulated under the same U.S. laws that govern the health, safety, and environmental impacts of conventional foods.
Another issue with drift involves the rights of near-by farmers who choose not to use a particular herbicide, noted Mortensen. If the herbicide keeps drifting into adjacent fields and killing crops, farmers may be forced to purchase it to avoid going out of business. To be fair, Dow has conducted research on ways to reduce particle drift, but Mortensen fears that farmers will not always use recommended herbicide application practices, especially if they are more costly.

In the case of Bt crops, which are engineered to manufacture a natural insecticide produced by the bacterium Bacillus thuringiensis, the insecticide is produced in minute amounts by the plant itself, so farmers do not need to apply it to the surface of the plant, which greatly reduces drift.

A growing group of like-minded scientists advocate for weed control using integrated pest management practices—characterized by the use of multiple weed management approaches that are based on ecological principles. Such practices could include crop rotation, the use of cover crops and competitive crop cultivars, the judicious use of tillage, and targeted herbicide application.

“It’s not too late in some systems where Roundup resistance isn’t a problem yet to develop systems that are based on more integrated weed management principles,” said Roush. “Australian grain growers use two or three different tactics in the same growing season, only one of which is a chemical, to try to control annual ryegrass, which is a notorious pest. I think in the United States we’re going to have to move more toward that.”

**Decisions to Make**

More than 7 billion people live on Earth, and 870 million of them suffer from chronic undernourishment, according to the United Nations Food and Agriculture Organization. By 2050, the world population will be close to 10 billion, and the world will need to produce 70 percent more food to keep up with this growth.

The promise of GMOs includes providing more food—even more nutritious food—to a growing population. GMOs also can bring financial security to farmers. For example, GM technology adoption has increased crop yields by 22 percent and farmer profits by 68 percent (11). This, according to Ott, is the reason GMOs have been so widely adopted, especially by the poorest farmers.

But relying completely on GMOs is not the answer either. “We can never forget that farmers grow food to serve society, and society has a say in what type of food production systems we use,” said Ott. “GM foods are not the only solution, but they are an important tool in the toolbox to feed a growing population sustainably.” Indeed, much work remains to be done to ensure that fewer people go hungry and that all agricultural practices are conducted to minimize the impact on human health and the environment.

When the Pew Research Center published its survey results about the beliefs of the public versus scientists, Alan Leschner, CEO of the American Association for the Advancement of Science, told the Associated Press that “science is about facts; science is not about values.” He meant that science is a powerful tool that can lead us to understanding, but it can only take us so far. Only we, as thoughtful, ethical beings, can decide what science to do and what to do with the results of science. With GMOs, as with many technologies, science allows us to evaluate the risks and benefits. The question is, do the benefits outweigh the risks? What do you think?

**References**

7. 7: 123–149.

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The scientists quoted in this story have not received money from companies, such as Monsanto, Dow AgriSciences, Syngenta, or Bayer. The scientists feel that the data from the studies mentioned in this story speak for themselves about the costs and benefits of GMOs to humans and the environment. Here, they attempt to share those unbiased data with readers.