



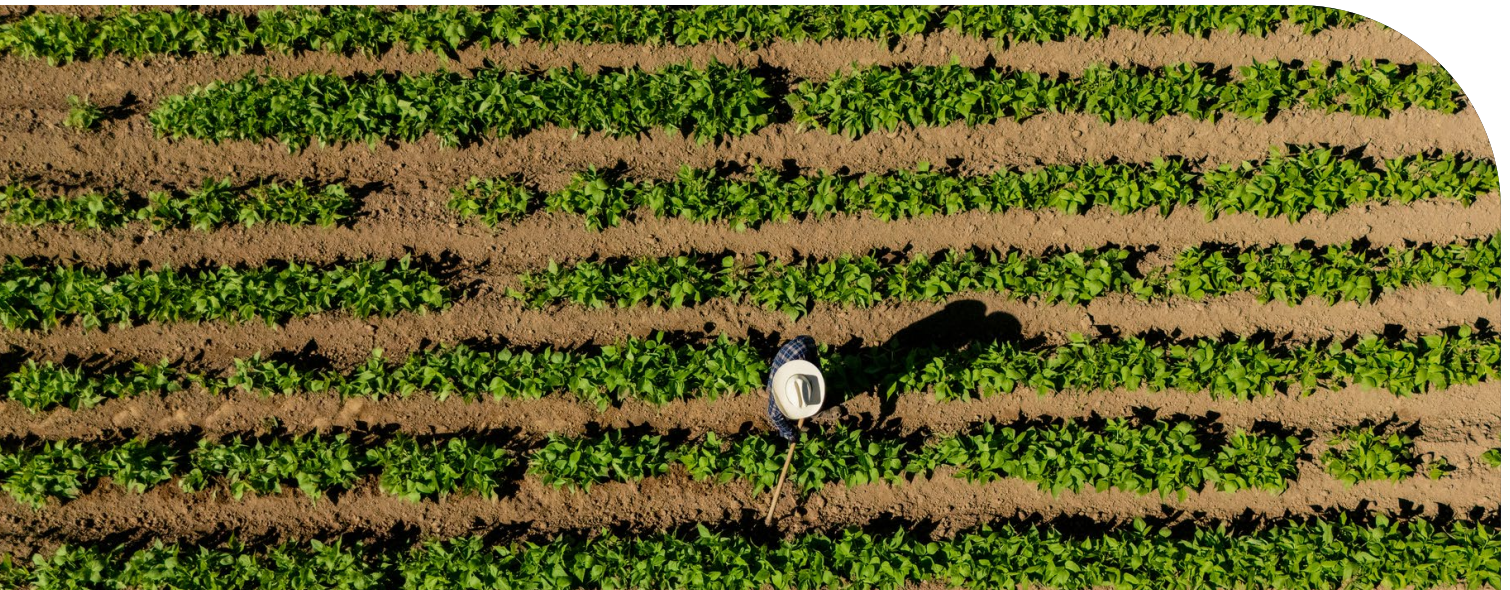
International
Food Information
Council

IFIC COMMUNICATOR'S GUIDE:
PLANT BIOTECHNOLOGY

JUNE 2026

CONTENTS

INTRODUCTION	3
BACKGROUND	4
THE ECONOMIC BENEFITS OF PLANT BIOTECHNOLOGY	10
PRINCIPLES FOR EFFECTIVE COMMUNICATION	11
KEY MESSAGES	15
FAQS	18
ADDITIONAL PLANT BIOTECHNOLOGY RESOURCES	20
COMMUNICATING ABOUT PESTICIDES	22
GLOSSARY OF TERMS	25
REFERENCES	29





INTRODUCTION

Navigating the food and nutrition landscape can be challenging for many consumers. The purpose of this guide is to inform and assist food and nutrition communicators in improving public understanding of plant biotechnology.

Significant scientific research has been conducted on plant biotechnology in the 30 years since the first genetically modified crop (GM or GMO) was brought to market. This research has carefully examined the safety and environmental impacts of GM crops, particularly the associated use of herbicides and insecticides. Researchers have also thoroughly studied the role of GM crops in reducing carbon emissions and improving sustainability in the agricultural sector. Additional research has explored the health effects of GM crops, such as nutritional qualities and allergenic potential. Many studies have also looked at agricultural yields (the amount of a crop harvested from a given area of land), economic costs and benefits to farmers, as well as the climate resilience of biotech crops.

As a result, **biotech crops are the most studied foods in history.**¹ The mounting evidence supports the consensus of numerous international regulatory bodies and health organizations that foods produced through biotechnology are as safe as conventionally produced foods.² The scientific literature also confirms

that biotech crops have tangible benefits for farmers, consumers, and the environment.^{3,4}

Meanwhile, to further address safety and transparency issues, an extensive regulatory framework has been created to oversee the development, commercialization, trade, and labeling of biotech food products, domestically and internationally. These regulatory schemes continue to be updated in response to rapid new developments in plant biotechnology and plant breeding innovations such as genome editing, as well as biopesticides and biofertilizers, tissue culture and micropropagation, and synthetic biology.

This guide seeks to accomplish two main objectives:

1. **Provide communicators with up-to-date, evidence-based information about the current state of plant biotechnology in the U.S. and globally;** and
2. **Equip them to communicate effectively with their intended audiences.**

BACKGROUND

OVERVIEW

Biotechnology brings together our rapidly expanding and evolving knowledge of living systems and technological processes to create useful products and applications in agriculture, health care, and environmental management. Plant biotechnology, specifically, provides us with an array of tools that can address many of the challenges facing global society: food and nutritional security, environmental sustainability, climate resilience, and economic equity.

For thousands of years, farmers have shaped the foods we eat by selecting plants with desirable traits, such as better taste, higher yields, or resistance to disease—long before anyone understood genes or DNA. As science advanced in the 20th century, researchers learned how inheritance works at the molecular level, which made plant breeding more precise and predictable. Biotech or genetically modified (GM) crops are a modern extension of this long history, using today's tools to introduce new characteristics. While the methods are newer, the goal remains the same: improving crops to better meet human needs and environmental challenges.

Plant biotechnology is one of the most exciting, revolutionary scientific breakthroughs of our time, marked by innovation and real-world problem solving. Its full potential is only beginning to emerge, offering us new opportunities to transform agricultural and food systems throughout the world.

BIOLOGY BASICS

All living things are comprised of trillions of different types of microscopic cells. Cells contain genetic material in the form of DNA (deoxyribonucleic acid), a molecule that contains genetic instructions for the development, functioning, and reproduction of living organisms, and RNA (ribonucleic acid), a molecule that carries genetic information from DNA to the cell's protein-making machinery. RNA is then translated into proteins, which include biological catalysts known as enzymes, and are integral for nearly all cell functions.

A gene's DNA sequence is transcribed into a messenger RNA (mRNA) molecule within the cell's nucleus. The mRNA molecule travels to the cell's cytoplasm, where it finds ribosomes, which read the genetic code and link amino acids together in the correct sequence to produce proteins, a process known as protein expression. Protein expression is necessary for many cell functions.

Scientists use various tools to change protein expression to increase or decrease the specific proteins produced by an organism or introduce genes that encode for new proteins to achieve desired traits, or characteristics. The choice of tools is usually governed by one or more factors, such as research goals, timeliness, precision, effectiveness, cost, efficiency, and ease of use. Scientists often choose to use plant biotechnology tools because they offer a level of versatility, speed, and predictability not found in conventional breeding methods.

In terms of agriculture, products resulting from use of breeding or biotechnology can be seeds, such as those that grow into plants with inherent protection against certain insect pests or weather conditions, and plant tissue, such as cassava roots that are not susceptible to specific plant diseases. Resulting products can also be whole foods, like non-browning apples and vitamin-rich purple tomatoes.

THE LANGUAGE OF PLANT BIOTECHNOLOGY

Many different words, terms, and phrases are used to express the science and practice of plant biotechnology, or biotech. Understanding the nuances and using the correct terms can help address misinformation and build a communicator's credibility.

In terms of food labeling, the U.S. government has chosen the official phrase bioengineered when speaking of biotechnology, as in, "bioengineered food" or "contains a bioengineered food ingredient".⁵ Most farmers, policy makers, scientists, communicators and consumers use other broad and specific terms, including GMOs (genetically modified organisms), genetically modified (GM), genetically engineered, transgenic, molecular biology, RNA interference (RNAi) technology, and recombinant DNA techniques.

These terms are often used interchangeably, yet they mean different things. While they are all techniques for modifying DNA, they vary in their approach and are subject to different regulatory processes. It is useful to understand what these terms generally mean, their differences, and how they are used to promote effective science communication. (Note: **A Glossary Of Terms** is also provided in this document and defines larger list of relevant words.)

Conventional breeding is the process by which scientists and farmers improve crops by selecting plants with desirable traits and crossing them with other plants to combine those traits over multiple generations. It relies on natural reproductive processes—such as hand-pollinating plants with complementary characteristics—and can take many years to produce stable new varieties with improved yield, disease resistance, or other useful characteristics or traits.

Genetic engineering is a broad term often used interchangeably with the term genetic modification (GM) to reference organisms' recombinant DNA technology.

Recombinant DNA technology is used to make transgenic organisms by combining DNA sequences from different sources to create new DNA molecules. One example is Golden Rice. Scientists used recombinant DNA techniques to insert genes that biofortify rice with beta carotene to address vitamin A deficiencies in vulnerable populations subsisting on grain-based diets. Another example is reducing the use of insecticides by introducing genes from the soil bacterium *Bacillus thuringiensis* (Bt) into corn DNA, which allows the plant itself to repel certain insects and pests.

Biostacked or "stacked traits" refer to GM plants that have been transformed with two or more genes impacting more than one trait. They offer broader agronomic enhancements and are intended to help farmers improve productivity by addressing more than one problem at a time, such as insect pests, diseases, weeds, and environmental stresses.⁶ An example is corn that is drought-tolerant and insect-resistant.

GMO is a frequently used acronym that stands for genetically modified organism. It is not a scientific term but has gained wide use in popular culture. Transgenic products—those with an incorporated foreign gene (i.e. a gene from outside the plant's gene pool)—are considered GMOs because the resulting organism has an added DNA sequence that would not naturally occur through conventional breeding methods. GMO is often used interchangeably with the abbreviation GM (genetically modified).

RNA interference (RNAi) technology is a gene-silencing method that uses small interfering RNAs to target and alter specific messenger RNA molecules, preventing protein synthesis. An example is the non-browning Arctic Apple, which works to reduce food waste by introducing a piece of the apple's own DNA to "silence" the gene responsible for the polyphenol oxidase (PPO) enzyme, which causes browning when apples are sliced or bruised. Although no foreign genetic material was introduced, the Arctic apple is regulated as a GMO because it contains a modified version of the apple's own PPO gene.

Bioengineered is a specific regulatory term used in the labeling disclosure of bioengineered foods in the U.S. It refers to food that contains genetic material modified through in vitro recombinant DNA techniques that could not have otherwise been obtained from conventional breeding or in nature.

COUNTRIES APPROVING GENETICALLY MODIFIED (GM) CROP CULTIVATION

MORE THAN 30 COUNTRIES HAVE APPROVED GM CROP CULTIVATION SINCE 1996. SEE WHERE GM CROPS ARE APPROVED FROM 1996 TO 2024.



Adapted from ISAAA (www.isaaa.org)

Beyond the U.S., additional GM crops have been approved and are being grown in other regions of the world to address locally specific agricultural, nutritional, and environmental challenges. These include insect-resistant eggplant and cowpea grown by smallholder farmers in parts of South Asia and Africa, biofortified rice developed to improve vitamin A intake in populations with limited dietary diversity, and disease-resistant crops such as virus-tolerant papaya and beans. The adoption of these crops reflects regional priorities, dietary staples, and regulatory frameworks, underscoring that biotechnology applications vary globally based on local needs rather than a one-size-fits-all approach.



GENETICALLY MODIFIED (GM) CROPS APPROVED FOR USE IN THE **U.S. FOOD SYSTEM**



Corn: Widely grown GMO crop used in many food ingredients (corn syrup, cornstarch, corn oil) and animal feed. Certain GMO sweet corn varieties are sold fresh.



Soybean: Major GMO crop used for soybean oil, lecithin, protein ingredients, and animal feed.



Canola: GMO canola varieties grown for canola oil and animal feed.



Cotton: GMO cotton grown for fiber and cottonseed oil used in foods.



Sugar Beet: GMO sugar beets contribute to a large share of packaged sugar.



Alfalfa: GMO alfalfa primarily used as animal feed.



Papaya: Certain virus-resistant GMO papaya varieties are sold fresh.



Potato: GMO potatoes with traits such as reduced bruising and browning have been approved and marketed.



Apple: Bioengineered apples (e.g., non-browning varieties) are available in U.S. markets.



Summer Squash: Some virus-resistant summer squash varieties have been commercialized.



Pink Pineapple: A GMO pineapple developed with unique flesh color has been introduced to the consumer market.



PLANT BIOTECHNOLOGY REGULATIONS & LABELING

Government bodies around the world recognize that agriculture is vital for feeding people and have adopted laws and regulations to ensure food production is safe. Specifically, many countries have established regulatory systems that govern how genetically modified (GM) crops are researched, developed, tested, labeled, and traded. These rules are designed to ensure that GM products are safe for people and animals and do not pose risks to the environment.

This guide references United States (U.S.) regulatory frameworks for clarity, while recognizing that other countries may take different approaches, ranging from product-based, science-driven systems to more precautionary, process-based models.

U.S. & GLOBAL REGULATORY FRAMEWORKS

Communicators must acknowledge any potential safety concerns while also helping audiences understand that there are robust regulatory and safety processes in place to ensure safety of GM crops.

U.S. and global regulatory frameworks focus primarily on a pre-market assessment of transgenic organisms (i.e., GMOs), as transferring genes across species is perceived to pose potential health and environmental risks.

In the U.S., the Department of Agriculture (USDA), Food and Drug Administration (FDA), and Environmental

Protection Agency (EPA) regulate plant biotechnology products under a **Coordinated Framework**. The USDA Animal and Plant Health Inspection Service (APHIS) manages import, movement, and environmental release of genetically engineered organisms (GMO). The FDA regulates all foods derived from plants, including GM plants, for human and animal consumption. The EPA regulates pesticides and other products used in conjunction with GM crops and evaluates the potential for environmental risks.

Globally, GM crops are managed by national regulations, international guidelines, and various regulatory philosophies ranging from risk-based approaches to precautionary frameworks. The current regulatory environment for GMOs directly impacts commercialization and international trade.

TRANSPARENCY THROUGH LABELING

Food and beverage labeling provides transparency to consumers. Many countries have mandatory post-market regulations such as labeling laws for GMOs. Labeling laws vary widely by national jurisdiction. In the U.S., foods that contain detectable genetic material that has been modified through in vitro recombinant DNA techniques and cannot be created through conventional breeding or found in nature must have the USDA Agricultural Marketing Service (AMS) bioengineered label or contain words stating “bioengineered” or include a QR code for consumers who desire more information.⁷



WHAT ARE **ADVANCED PLANT BREEDING INNOVATIONS?**

Changes in crop characteristics or traits can be made by using conventional breeding as well as advanced plant breeding innovations like genome editing by introducing, deleting, silencing, activating, and rearranging specific genomic sequences.

Gene editing is a way scientists make small, targeted changes to a plant's existing DNA—like fixing a typo in a sentence that's already there. It often involves turning a gene “on” or “off” or tweaking it slightly, without adding DNA from another species. For this reason, gene and genome editing is typically considered to be no different than conventional breeding and are often classified as “plant breeding innovations or PBIs.”

Genome editing is a broader term that includes gene editing and refers to tools that allow scientists to make targeted changes anywhere across an organism's entire set of DNA (its genome). With gene and genome editing, breeders work with the plant's own genetic material, just more precisely and efficiently than conventional breeding allows.

CRISPR, which stands for **Clustered Regularly Interspaced Short Palindromic Repeats**, is one of many genome editing tools that allow scientists to cut, add, or alter DNA. It is less expensive and more versatile than earlier tools and has a wide range of applications in agriculture, medicine, and research. For example, CRISPR is being used, among many other applications to develop disease-resistant varieties of cacao, the key ingredient of chocolate.

WHAT IS THE DIFFERENCE BETWEEN GMO CROPS AND CROPS PRODUCED USING GENOME EDITING?

Genetic diversity drives selection of desired traits; this is the foundation of even the earliest breeding techniques to develop improved crops. In a GMO crop, there is the **addition** of desirable genes from another species resulting in a plant with new and beneficial characteristics. Genome editing uses a DNA editing tool, such as CRISPR, to target a deletion or replacement at a specific location **within** the cell's DNA.

ADVANCED PLANT BREEDING INNOVATION REGULATION

Regulators in some countries and regions, such as the European Union, are currently determining whether products created through advanced plant breeding innovations, such as genome editing, should be regulated more like conventionally bred plants agriculture or face the same scrutiny as GMOs. In many countries, the decision on whether a genome edited plant should be regulated as a conventionally bred plant or as a GMO is based on the presence of absence of foreign DNA in the resulting plant. Still, alternative regulatory approaches exist that make this regulatory oversight decision based on the extent of the edit, characteristics of the trait, whether the traits could be “naturally” achieved through traditional breeding, and the potential health and environmental hazards of the final product.⁸

THE ECONOMIC BENEFITS OF PLANT BIOTECHNOLOGY

Farmers, consumers, and governments typically share values related to economics, such as keeping food affordable, improving incomes in rural areas to build resilient communities, and maintaining economic competitiveness in world trade. Like any profession, farming is not sustainable unless it is profitable.

This is a key issue as the number of farms continues to decrease worldwide while the demand for food increases due to global population growth. Biotechnology can support farm profitability by increasing yields, promoting sustainable farming practices (e.g. no-till farming, reduced insecticide sprays), and reducing production costs.

The following points address some of the **economic benefits of plant biotechnology**:



Increased yields. GM crops have been proven to increase crop yields by at least 20%— often more.⁹ Increased yields create higher supply volumes and achieving abundant supply volumes is a key contributing factor of lower consumer food prices and economic stability for farmers. This also allows farming without the need to increase land use for agriculture, a key environmental benefit.



Improved incomes. Globally, farmers who planted GM crops significantly increased their incomes for the period 1996–2018. Over the 1996–2020 period, farmers in developing countries received \$5.22 as extra income for each extra dollar invested in GM crop seeds; farmers in developed countries received \$3 as extra income for each extra dollar invested in GM crop seeds. The average return across all GM crop growers represents \$3.76 in extra income for each extra dollar invested over the 1996–2020 period.¹⁰



Increased economic value. Research estimates that biotechnology applications could generate up to \$1 trillion in economic value between 2025 and 2040 in the global sectors of agriculture, chemicals, personal care, and transportation.¹¹



Expanding markets. Trade barriers targeted at GMOs reduce access to food, limit farm revenues, and increase overall prices. When countries lift trade barriers, imports would increase by an estimated 14.7%, which would result in an estimated 4.9% reduction in food prices. Conversely, a trade barrier decreases access to imports by almost 10% and food prices increase by 1%. A 1% increase in food prices translates to \$14 billion per year as well as welfare losses per year ranging from around \$200 million to approximately \$5 billion domestically and around \$800 million to about \$6 billion globally.¹²



PRINCIPLES FOR EFFECTIVE COMMUNICATION

Though awareness of genetics and DNA has increased due to the popularity of kits that let people determine their ancestry and the breed of their dogs, general knowledge about genetics remains low.¹³ Though the information shared about plant biotechnology must be based on the current body of evidence, it is most effective when it is delivered with the context of shared values and the benefits they provide.

Decades of misinformation about GMOs have shaped public opinion and led to strict regulations in some regions, especially in parts of Europe and Africa.¹⁴ Given the misinformation surrounding plant biotechnology, it is tempting to believe that simply sharing accurate information can broaden perspectives and change minds. Yet facts alone are usually not enough, especially when communicating about emotional, highly charged topics like food. So, it is also critical to listen, acknowledge concerns, and connect on an emotional or personal level.

The International Food Information Council (IFIC) Guidance Document **Understanding & Interpreting Food & Health Scientific Studies** offers insights for credible and effective science communication, inspiring consumer trust. You can employ these strategies when talking about plant biotechnology, including:

- Consider the audience's wants and needs
- Ask questions to assess the audience's knowledge, attitudes, and beliefs
- Align around key values
- Keep the facts simple and contextualized
- Minimize the repetition of misinformation

KEY CONVERSATION CONCEPTS

Addressing the value of biotech crops to farmers, consumers, and the environment can improve understanding of biotech crops. The following concepts and corresponding messages can be helpful when communicating about plant biotechnology.

- Use Positive Framing
- Share The Story
- Acknowledge Consumer Interests & Shared Values
- Focus On Biotech Benefits & Beneficiaries

USE POSITIVE FRAMING

Negative words and experiences persist longer in our consciousness than positive ones, which is why disinformation campaigns are often so effective.

Example: Instead of saying, “no one has been harmed by eating GMO foods,” say, “scientists generally agree that GMO foods are as safe as their conventional counterparts.”

OR “GMO technology is not only safe and regulated—it also provides us with a farming tool that has positive environmental and social impacts.”

Another approach could include not mentioning the word “safe” and simply saying, “GMO technology has many benefits for both people and the environment.”



SHARE THE STORY

Focus on presenting credible information and a different perspective, such as the technology’s value as viewed from a farmer or a scientist perspective, creating a compelling human-interest story. Examples include:

A scientist in Hawaii was motivated to use plant biotechnology to develop virus-resistant papaya when he saw communities losing access to a vital crop, as well as smallholder farmers in his community losing their crops and livelihoods as the virus spread unchecked through their orchards.

The African Agricultural Technology Foundation facilitated transfer of the gene for Bt cowpea from industry to African researchers at no cost. This led to development of **locally adapted varieties** of GM cowpea that resist the pod borer insect pest, leading to higher yields, lower pesticide use, and better farmer incomes. The new varieties developed under these agreements are typically released through the collaborative efforts of numerous organizations or are owned by public entities like the **Savanna Agricultural Research Institute**.

Public sector scientists and public-private partnerships are leading work focused on improving conditions in low- and middle-income countries, particularly in the Global South. Extensive research has been completed and is currently under way to address myriad social and environmental issues through biotechnology, including food security,¹⁵ better nutrition,¹⁶ reductions in pesticide use,¹⁷ climate change^{18,19} improved livelihoods and health for smallholder farmers,²⁰ and overall sustainability.²¹

ACKNOWLEDGE CONSUMER INTERESTS & SHARED VALUES

Because everyone depends on food, we are all consumers—farmers, processors, retailers, and shoppers alike. Recognizing this shared identity creates a foundation for communicating how plant biotechnology can support the values we all hold. Effective communication should emphasize the common priorities that connect consumers and food system stakeholders to the goals of biotechnology.

These shared values include consumer-driven interests like convenience, novelty, health, and affordability, as well as broader commitments to environmental sustainability, animal welfare, and maintaining the integrity of natural resources. By framing biotechnology through these shared values, communicators can better illustrate how innovation aligns with what matters most to people across the food system.

GENERAL CONSUMER INTEREST

Though the early biotech crops primarily addressed farmer needs with traits like insect resistance and herbicide tolerance, new developments are more focused on traits and applications that interest consumers. Here are some specific examples of consumer-forward traits:

GM or Biotech products with **direct consumer appeal** include non-browning apples, non-bruising potatoes, purple tomatoes with a high antioxidant content, soybean oil without trans fats, and vitamin A-rich Golden Rice.

Meat alternatives, such as plant-based burgers²² and lab-grown cellular meat,²³ are enhanced by biotechnology, which improves the taste and texture of these foods. **International Food Information Council (IFIC) research** has found that 42% of U.S. consumers would be interested in trying cell-cultured meat.

Lower food prices can be achieved through biotech crops that increase yields while reducing the use of expensive inputs, such as fertilizer, water, and pesticides.²⁴

Food waste and food safety benefits, such as extending the shelf life of fresh produce to reduce food waste, inhibiting the growth of pathogens,²⁵ and reducing or eliminating allergens,²⁶ are consumer-forward traits.

Biotechnology has led to other improvements that indirectly benefit consumers. They include making **antibiotic production** more efficient through microbial fermentation, improving insulin production, and

producing new livestock vaccines for diseases such as foot and mouth disease and rabies.²⁷

ENVIRONMENTAL SUSTAINABILITY

Ensuring a healthy planet for present and future generations is a value that consistently resonates with consumers. It is an area where the benefits of biotechnology have been well-documented and significant new research is under way. Here are some specific examples:

Water use efficiency can be improved through plant biotechnology, which has produced widely grown crops like corn that can survive drought conditions without reducing yields.²⁸ This is crucial, considering that 70% of global freshwater resources are used for agriculture.²⁹

Agriculture accounts for about 25% of the **greenhouse gas (GHG) emissions** that are warming the planet.³⁰ Biotech crops have been documented to reduce GHG emissions by cutting the number of pesticide applications and facilitating the adoption of **regenerative agriculture** and **reduced- and no-till systems**, which resulted in less on-farm fuel use. In 2020 alone, that savings was equivalent to taking 15.6 million cars off the road for a year.³¹ Other sustainability benefits include enhanced soil quality and reduced levels of **soil erosion**, further reducing emissions by keeping more carbon in the soil, also known as **carbon sequestering**.

Regenerative agriculture is supported by plant biotechnology, which reduces the need for soil tilling and chemical inputs and encourages the use of **cover crops**. These practices build soil fertility and contribute to climate-resilience and sustainable yields.³²

Genetically modified crops are being developed for phytoremediation—detoxifying or absorbing and accumulating **pollutants** in the soil—to improve soil quality at polluted sites.³³ Research is also under way on engineering zebra fish and fruit flies to detoxify mercury, a toxic trace metal, in food webs.³⁴

Gene stacking is being used to accelerate research on plants that could be used as aviation fuel and in other sustainability applications.³⁵

THE CONCEPT OF “NATURAL”

Consumers are attracted to the concept of “natural.” Genetic engineering replicates a process that has been occurring in nature for millions of years. Some bacterium and viruses can naturally insert their genes into plant cells, resulting in new traits, through a process known as horizontal gene transfer. Sweet potatoes, for example, are natural GMOs.³⁶

FOCUS ON BIOTECH BENEFITS & BENEFICIARIES

Seek to humanize biotechnology by focusing on the impact of a trait as well as its benefits and beneficiaries, rather than only the technology that achieved it. This is especially important when the trait benefits **smallholder farmers**, who produce a third of the world’s food. Here are some specific examples that address the direct benefits and beneficiaries of plant biotechnology:

Eggplant, or brinjal as it is known in South Asia, is a dietary staple in Bangladesh and an important cash crop for smallholder farmers. **Bt eggplant** was developed to provide farmers in Bangladesh with a brinjal variety that can successfully resist the destructive fruit and shoot borer pest that often caused 100% crop loss. Rather than get into the scientific process of how the Bt trait was introduced, talk about what it means for the farmer. He/she can now dramatically reduce the use of pesticides. By reducing the need to spray, farmers save resources, and both farmers and consumers have less exposure to pesticide hazards. Since Bt brinjal has less pesticide residue and insect damage, farmers earn higher prices at the market, generating money that can pay school fees and otherwise improve the family’s life. The farmer can even save the seeds to grow next year’s crop.³⁷



Papaya that **resist the ringspot virus** were developed to address serious crop losses that were harming smallholder farmers in Hawaii and increasing the use of pesticides. The ringspot virus had reduced production of Hawaii’s fifth most important crop by 40% before the biotech papaya was commercialized in 1998.³⁸ Scientists turned to genetic modification after they failed to find solutions to the problem with conventional plant breeding methods.

Climate-smart agriculture depends on biotechnology for development of crops that can tolerate climate-related stresses, such as drought, heat, and pests. This is particularly important in regions like Africa, which are experiencing the brunt of these impacts.³⁹ Examples include promoting deeper root growth to improve drought tolerance in rice,⁴⁰ enhancing salt tolerance in rice⁴¹ and soybeans,⁴² as well as other crops, and optimizing the efficient use of nutrients (fertilizer).⁴³

Non-browning apples were developed to reduce food waste, as bruising can result in product losses up to 50%,⁴⁴ and encourage more healthful fruit consumption by offering on-the-go consumers and school children a convenient fresh-sliced option.

High-yielding crops can protect biodiversity, support the environment, and improve farmer livelihoods because more food can be produced on the same amount of land, reducing the need to convert new acreage to farmland. Biotech crops deliver documented benefits in this area. A meta-analysis of the impacts of GM crops found they increased crop yields by 22% and farmer profits by 68%, on average.⁴⁵



KEY MESSAGES

The following key messages directly address how plant biotechnology can support consumer values and interests.

OVERALL KEY MESSAGES



Plant biotechnology combines innovative technology and biology to provide tangible benefits to farmers and consumers.



Crops produced through plant biotechnology, or genetically modified (GM/GMO) crops, provide safe and nutritious foods, and in some cases, offer added nutritional benefits.



Foods and food ingredients derived from GMO crops are among the most studied and regulated in history, ensuring their safety for people, animals and the planet.



U.S. consumers are most likely to encounter GMO corn, soybean, canola, and sugar beets, as they are ingredients in many food and beverage products.



Knowledge empowers informed choices. Transparent disclosure of GM ingredients on food labels helps families make informed decisions about their food.



INTEREST-SPECIFIC KEY MESSAGES

For more than 20 years, the *IFIC Food & Health Survey* has found that taste and price are the top purchase drivers, followed by healthfulness, convenience, and environmental sustainability. The following message points can help communicators discuss plant biotechnology and GM crops in context of these leading consumer purchase drivers.

TASTE

The **pink flesh pineapple** was developed with biotechnology while keeping consumer taste preferences in mind, as it is sweeter and less acidic than standard pineapple.

Nonbruising GMO potatoes help ensure that products like French fries retain their desired color and texture during processing and freezing.

HEALTHFULNESS

Soybean oil with more heart-healthy fats and no unhealthy trans fats is an example of how plant biotechnology can improve the healthfulness of commonly used foods.

The **nutritional quality** of foods can be enhanced through biotechnology, such as vitamin A-rich Golden Rice.

A purple tomato with higher levels of antioxidants linked to reduced risks of cognitive decline, heart disease, and cancer was produced through plant biotechnology.

Biotechnology can potentially be used to **eliminate allergens** in wheat and eggs.

SAFETY

GMOs are **carefully regulated through national and international policies** that ensure both their safety and wise management.

Global scientific authorities agree **GMO crops are as safe and nutritious** as their conventionally grown counterparts.

Biotech or GM crops **can reduce pesticide use** and the potential presence of pesticide residues.

Insect-resistant biotech crops reduce pesticide use, **protecting biodiversity and ecosystem conservation.**

Insect-resistant biotech crops reduce potential pesticide poisoning for farm workers and **enhance safety.**



PRICE

Biotech crops help farmers grow more food, which can help keep food prices low.

Biotech foods like **non-browning apples and bruise-resistant potatoes** cut down on food waste and wasting a food purchase.

The first biotech products were developed to help farmers manage insect pests, weeds, and plant diseases that cause **significant crop losses** and contribute to high food prices.

Herbicide-tolerant biotech crops help reduce farmers' costs for weed control, improving farm profitability, and helping to **keep food prices low**.

CONVENIENCE

Because of its non-browning trait, the GMO apple can be sold pre-sliced, rather than whole, making it an easy choice for lunches, snacks, and travel.

ENVIRONMENTAL SUSTAINABILITY

Biotech tools help farmers grow crops safely, more efficiently, and sustainably. Biotech crops help farmers **use less water, fertilizer, and pesticides**—saving money and protecting the environment.

Growing biotech crops **reduces the greenhouse gas emissions** that contribute to climate change.

Crops developed through biotechnology **support regenerative farming** practices that rebuild soil and store carbon.

Insect-resistant biotech crops naturally suppress insect pest populations, creating a **“halo effect”** of protection that benefits nearby organic and conventional crops.

By producing bigger harvests, biotech crops can **reduce the need to bring new land into agriculture**. This protects wild areas and supports biodiversity.

Biotechnology can **help protect the world's food supply from climate change impacts**.

Many biotech breakthroughs—from salt-resistant rice to drought-tolerant soybeans—**could help protect the food supply from climate extremes**.



FAQS

The following FAQs and science-based answers can help you directly address common questions, share the story of plant biotechnology and emphasize shared values, while also reinforcing your credibility as a knowledgeable resource.

Is biotechnology unnatural?

Humans have been selectively breeding plants and animals for countless millennia, so all domesticated plant species—and even our pet dogs and cats—are technically genetically modified. Genetic modification (GM) replicates a process that has been occurring in nature for millions of years as bacteria and viruses regularly shuttle genes between different species.

This has been documented in that sweet potatoes are natural “GMOs.” The same technology that is used to make GM crops (a bacterium called *Agrobacterium tumefaciens*) was found naturally occurring in the genomes of all sweet potatoes, which are eaten by millions of people worldwide. This means that sweet potatoes have been making bacterial proteins since their domestication more than 8,000 years ago.⁴⁶

Why does the U.S. allow GMOs when they’re banned in Europe?

All European nations import GM commodity crops, like corn and soy, for livestock feed, as well as packaged foods for humans that contain GMO ingredients. A limited number of European Union member states currently grow GM corn varieties approved under EU law.

Consistent with other regulatory agencies globally, European scientific authorities have concluded that

the GM crops currently authorized for cultivation and import do not pose greater risks to human health or the environment than conventionally bred crops.^{47,48}

Why haven’t there been human studies on the safety of eating GMOs?

Humans have eaten billions of servings of biotech foods over the past 30 years with no documented adverse effects. Governments everywhere employ strict biosafety protocols to ensure that any new biotech product poses no threat to human or animal health, or the environment. These protocols include laboratory and field tests that may span many years. In this way, the resulting plants and foods are far more thoroughly tested than their conventional counterparts. Hundreds of scientific papers have assessed the safety of GM crops, and the vast majority found they are nutritionally equivalent to their conventional counterparts.⁴⁹

Do biotech crops contaminate organic crops and heirloom varieties?

Biotech crops can co-exist with crops grown using other production methods. Some producers choose to grow a combination of GM, conventional, and organic crops on their farms, depending on market demand and price, proximity of storage and processing facilities, climatic conditions, and other factors.⁵⁰ The GM papaya is a good example of co-existence because it suppresses the ringspot virus in agricultural areas,

making organic papaya production possible. Research has found that by suppressing pest insect populations, insect-resistant GM crops can create a “halo effect” of protection that benefits nearby organic and conventional crops.⁵¹

How will I know if I'm eating food produced through biotechnology?

Many countries, including the U.S., China, Japan, and EU member states, require genetically modified foods or foods that include ingredients derived from biotech crops to be labeled, with laws varying by regions. In the U.S., labels may state “made with bioengineered ingredients” or include a QR code for consumers who desire more information.⁵²

Why can't farmers save GMO seeds?

It is true that patented GMO seeds can be protected by contract law and intellectual property rights, meaning farmers must pledge not to save them and replant.⁵³ Of note, hybrid seeds, which have been around for decades, also need to be purchased each season because they do not “breed true” (produce offspring with the same traits of the parent). So, this is not a new concept for many farmers.

Farmers choose to purchase specific seed varieties (GMO, conventional, organic) based on many factors (improved yield, desired market price, etc.). In addition, in several public sector projects, such as the Hawaiian papaya, insect-resistant eggplant in Bangladesh, and Water Efficient Maize for Africa, farmers are free to save and share GMO seeds, and no royalties are charged.

Contrary to some claims, no biotech seed on the market contains “terminator” traits that prevent a seed from sprouting. The United Nations Convention on Biological Diversity introduced an international moratorium on such traits, known as genetic use restriction technology (GURTs), in 2000.⁵⁴

Aren't GMOs just a corporate plot to control the world's food supply?

No. In fact, smallholder farmers in developing nations are increasingly choosing GMOs, devoting more land to growing biotech crops than developed nations.⁵⁵

In 2019, some 17 million farmers chose to grow biotech crops because they increased yields and reduced production costs, thus raising incomes.⁵⁶

Is organic food safer than food produced using GMOs?

No. Both production methods share more similarities than differences. For example, organic and GMO production systems can use pesticides. In fact, organic growers are allowed to use certain types of pesticides that some GMOs minimize. One example is a GM potato resistant to late blight disease (water mold), which does not need toxic substances like copper sulfate or other fungicides which are often used to control blight in organic farming. Of not, regardless of the production method used to grow it, all food sold in the U.S. must meet federal standards related to pesticide residues.⁵⁷

Humans have eaten
**billions of servings
of biotech foods**
over the past 30
years with no
documented
adverse effects.

Do we really need GMOs to feed the world?

Western nations, which have access to agricultural innovations, often enjoy high yields. It is one more tool in the farmer's toolbox that allows them to do what is best for their farms. The goal now is to ensure that lower- and middle-income countries can access that same innovation to improve their own yields, feed their populations, and build their economies through a strong agricultural sector. Biotechnology is an innovation that also supports multidisciplinary scientific research, as well as the health and energy sectors.



ADDITIONAL RESOURCES

AUTHORITATIVE STATEMENTS

Healthfulness and food safety are important concerns for consumers. When communicating about biotechnology, it can be reassuring to audiences to learn that some of the world's most prestigious scientific and health organizations agree on the healthfulness and safety of biotechnology in food and agricultural systems.

National Academies of Sciences, Engineering, and Medicine (NASEM): "There is no validated evidence that foods made from GMOs are less healthy than non-GMO foods. No evidence has validated that eating food with GMO ingredients is harmful."⁵⁸

European Academies Science Advisory Council (EASAC): "There is no validated evidence that GM crops have greater adverse impact on health and the environment than any other technology used in plant breeding."⁵⁹

European Commission: "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."⁶⁰

American Medical Association (AMA): "There is no evidence that unique hazards exist either in the use of rDNA techniques or in the movement of genes between unrelated organisms. The risks associated with the introduction of rDNA-engineered organisms are the same in kind as those associated with the introduction of unmodified organisms and organisms modified by other methods. Assessment of the risk of introducing rDNA-engineered organisms into the environment should be based on the nature of the organism and the environment into which it is introduced, not on the method by which it was produced."⁶¹

American Association for the Advancement of Science (AAAS): “The World Health Organization, the American Medical Association, the U.S. National Academy of Sciences, the British Royal Society, and every other respected organization that has examined the evidence has come to the same conclusion: consuming foods containing ingredients derived from GM crops is no riskier than consuming the same foods containing ingredients from crop plants modified by conventional plant improvement techniques.”⁶²

International Society for Plant Pathology (ISPP): “GM technology, where adopted, is widely regulated and no evidence has been reported of adverse consequences for human health.”⁶³

Academy of Nutrition and Dietetics (AND - formerly American Dietetic Association): “It is the position of the American Dietetic Association that agricultural and food biotechnology techniques can enhance the quality, safety, nutritional value, and variety of food available for human consumption and increase the efficiency of food production, food processing, food distribution, and environmental and waste management.”⁶⁴

Union of the German Academies of Science and Humanities: “The report concludes that food derived from GM plants approved in the EU and the US poses no risks greater than those from the corresponding conventional food. On the contrary, in some cases food from GM plants appears to be superior with respect to health.”⁶⁵

Health Canada: “We do a thorough safety assessment of all novel GM foods to make sure that they are as safe and nutritious as foods already sold in Canada.”⁶⁶

World Health Organization (WHO): “Currently available GMO foods are not likely to present risks to human health.”⁶⁷

OTHER SCIENTIFIC RESOURCES

Many organizations and institutions provide evidence-based information on agricultural biotechnology.

(Links are provided, but they may be broken as websites evolve.)

African Agricultural Technology Foundation (AATF)

AgBio World

Council for Agricultural Science and Technology (CAST)

Ghent University

Michigan State University

National Institute of Health (NIH) National Center for Biotechnology Information (NCBI)

National Science Foundation (NSF)

International Service for the Acquisition of Agri-biotech Applications (ISAAA)

United Nations (UN) Food and Agriculture Organization (FAO)

United States Department of Agriculture (USDA)

United States Environmental Protection Agency (EPA)

United States Food and Drug Administration (FDA)

University of California, Davis

University of California, Riverside

University of Edinburgh, Roslin Institute

Virginia Tech Information Systems for Biotechnology (ISB)



COMMUNICATING ABOUT PESTICIDES

Pest and disease management are major concerns in agriculture because destructive insects, weeds, and microbial diseases can cause significant harm and losses to crops. Crop losses, and food prices, would be much higher if farmers did not practice any pest management. Weeds alone cause a 31.5% reduction in plant production, which translates to USD \$32 billion per year in economic losses.⁶⁸ These losses can contribute to higher food prices or undermine the economic viability of farming.

Farmers and ranchers use various tools to control pests, including crop rotation, soil management, biotech crops, as well as organic and synthetic pesticides. Pesticides are substances that are used against specific pests. They include **herbicides, insecticides, nematocides, fungicides, algacides, disinfectants, antimicrobials, rodenticides, insect growth regulators, and wood preservatives**. Both organic and conventional agriculture use pesticides. However, synthetic pesticides are not allowed in organic production unless they are specifically allowed.

Communicating about pest management can be challenging due to the scientific complexity of the topic, the diversity of agricultural practices, and the strong public interest in food safety. Because biotechnology innovations often intersect with pest- and weed-management tools, conversations about plant biotechnology frequently include discussions about pesticides.

Public attention to GMOs increased significantly following the introduction of the first GM crops

in 1996. Interest grew further around the time of California Proposition 37 in 2012, which proposed mandatory labeling of genetically modified foods. Subsequent advocacy efforts, policy debates, and legal actions contributed to continued public dialogue about both plant biotechnology and pesticide use. Today, glyphosate remains one of the most widely used herbicides globally, and discussions about its role highlight the ongoing need for clear, evidence-based communication to support public understanding.

Those who oppose GMOs often link all biotech crops to intensive use of pesticides, even though some biotech crops decrease the need for pesticides. Additionally, most people are not well-informed about the regulation and use of pesticides in agriculture. For example, nearly half of Americans believe that pesticides are not used in organic farming,⁶⁹ even though most organic producers use various chemicals to control weeds and insect pests and dozens of natural and synthetic pesticides are permitted under U.S. organic certification regulations.⁷⁰

PESTICIDE REGULATION & SAFETY

The U.S. Environmental Protection Agency (EPA) must ensure that all pesticides used on crops in the United States meet stringent safety standards laid out in the **Food Quality Protection Act (FQPA)**. FQPA requires an explicit determination that the use of a pesticide on crops is safe for children. The EPA re-evaluates the safety of each pesticide every 15 years. EPA's continuous reevaluation of registered pesticides, combined with strict FQPA standards and an increase in the use of safer, less toxic pesticides, has led to an overall trend of reduced risk from pesticides.⁷¹

Over **99.8%** of foods sampled contained pesticide residues well below thresholds established by EPA.

The detection of a pesticide residue does not mean the food is unsafe. In fact, the U.S. Department of Agriculture (USDA) Pesticide Data Program (PDP) and current methods of detection detect residues at levels far lower than those that are considered health risks.⁷²

Over 99.8% of foods sampled contained pesticide residues well below thresholds established by EPA.⁷³ Additionally, the very small amounts of pesticides that may remain in or on fruits, vegetables, grains, and other foods decrease considerably as crops are harvested, transported, exposed to light, washed, prepared and cooked. In the U.S., imported foods must meet the same pesticide residue standards as domestically produced foods.⁷⁴

HERBICIDE TOLERANCE & INSECT RESISTANCE

Two of the most prevalent traits in biotech crops are herbicide tolerance (HT)—the ability of plants to withstand applications of herbicides used to control

weeds—and insect resistance, which gives a plant the inherent ability to ward off certain insect pests, thus reducing or eliminating the need for insecticide sprays.

Biotechnology critics often deride the advent of herbicide-tolerant (HT) crops because they do not see the value for consumers or the environment. Others believe HT was introduced solely to sell more herbicides. Others just oppose biotechnology in general, whether on moral or ethical grounds. Yes, these attitudes can shift when the discussion shares the perspective of a farmer, who may be facing crop and revenue loss, which can have serious livelihood impacts, especially in less affluent nations.

The details below offer additional information on the utility and pertinence of HT and insect resistant crops in farming:

A review of GM crop use from 1996-2016 found “[t]he adoption of GM insect-resistant and herbicide-tolerant technology has reduced pesticide spraying by 671.4 million kg (8.2%) and, as a result, decreased the environmental impact associated with herbicide and insecticide use on these crops (as measured by the indicator, the Environmental Impact Quotient (EIQ)) by 18.4%.⁷⁵ For context, this is equal to more than 1.6 times China’s total crop protection product use each year.

Insect-resistant (IR) crops were introduced at about the same time as HT crops. These biotech crops significantly reduce pesticide use, yet there is far less public awareness about their application in agriculture. Insect-resistance is conferred primarily through a specific gene found in *Bacillus thuringiensis*, (Bt), a naturally occurring soil bacterium commonly used as a dust or spray to control specific types of insects in organic farming. Genetic engineering confers the resistance directly to the plant. Approximately 87% of cotton acres and 83% percent of corn acres were planted with stacked-trait seeds—offering both herbicide tolerance and insect resistance—in 2024 alone.

Globally, over 100 million hectares (247 million acres) have been planted with Bt crops. Bt crops can support biodiversity protection and conservation because they

reduce insecticide use and does not harm beneficial insects or soil organisms.⁷⁶ Bt corn, soy, cotton, cowpea, and eggplant are currently being grown and have experienced strong farmer uptake in the countries where they are commercialized. In 2024, Bt corn accounted for about 84% of U.S. corn acreage, while 90% of U.S. cotton acreage was planted in Bt cotton.⁷⁷ About 90% of the cotton grown in India is Bt.⁷⁸

Potential farm worker poisoning, particularly among smallholder farmers in countries where pesticides are poorly regulated, remains a concern. Worker safety can be impacted by issues such as the proliferation of counterfeit products, inadequate worker training on proper application of crop protection products, and limited use of personal protective equipment. In India, for instance, a 50-70% reduction in pesticide applications on insect-resistant GM (Bt) cotton helped avoid several million cases of pesticide poisoning per year.⁷⁹

Farmers rank HT as a top desired crop trait because of the significant costs and productivity challenges associated with weed control. The HT traits have been introduced to corn, soybeans, cotton, sugar beet, canola, and alfalfa, with the first three crops widely adopted globally. Approximately 90% of U.S. corn acres were planted with HT seeds in 2024, while HT cotton acreage stood at 93% and HT soybean acreage hit 96%.⁸⁰ HT crops can also reduce the need to till soil, improving soil health and lowering production costs. Tilling is a way of manipulating soil, typically used prior to planting new crops, in order to mix organic material back into the soil and break down weeds. However, tilling releases carbon from the soil into the atmosphere. By practicing minimal or no-till techniques, carbon is left underground, enriching the soil and reducing greenhouse gas production.

INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM) has evolved as a critical component of agriculture today. IPM promotes the presence of beneficial insects, such as pollinators and those that prey on pests, and accepts a certain level of pest insects. IPM can significantly reduce pesticide use, protect beneficial insect species, and reduce the likelihood of pests developing resistance to crop protection products.

IPM uses science-based principles to help farmers monitor their crops for insect levels and respond with the most effective tools when an established threshold is breached. Tool examples include crop rotation, habitat modification, changing irrigation practices, and other physical, biological, chemical, and cultural controls. Insecticides are used as a last resort, generally with an emphasis on a low-toxicity product. Certain biotech or GM traits, such as Bt, can also be part of an IPM program.⁸¹

PESTICIDE INNOVATION

It can be helpful when communicating about pesticides to remind your audience that science is continuously evolving to improve the safety and efficacy of crop protection products. The following information points to current and future pesticide innovation:

Modern pesticides are often more effective at lower concentrations, meaning less of the chemical is needed to achieve the desired effect, reducing overall exposure.

Biopesticides, phytopesticides, and nanobiopesticides are derived from natural ingredients, such as microbes, plant extracts, minerals, insects, and pathogens. They typically target specific pests without harming beneficial insects, can be easily sourced without the need for expensive chemicals, and are environmentally sustainable without residual effects. Additionally, they can be incorporated into integrated pest management programs.^{82,83}

New formulations and active ingredients are being developed that are more targeted to specific pests and less harmful to non-target organisms, including humans and beneficial insects. For example, **nanotechnology** is revolutionizing insecticide applications by creating nano-sized particles that improve the absorption and effectiveness of active ingredients, enhancing the efficiency of pest control while reducing the amount of chemicals released into the environment.⁸⁴

Emerging technologies like drones, remote sensors, and artificial intelligence can monitor crops in real time, helping farmers to optimize the timing of inputs and deliver crop protection products in precise quantities and locations, thus improving efficiency and safety, reducing waste, lowering the risk of pesticides drifting into unintended areas, and cutting costs.⁸⁵

GLOSSARY OF TERMS

Agricultural Biotechnology: Encompasses a range of tools, including traditional breeding techniques (e.g., selective breeding), that are used to improve plants, animals, and microorganisms for agricultural purposes. Modern biotechnology includes tools such as genetic modification or engineering.

Bacillus thuringiensis (Bt): A soil bacterium that produces toxins that are deadly to some pests. The ability to produce Bt toxins has been engineered into some crops.

Bioinsecticide: Any material used in insect control that is derived from living organisms, such as bacteria, plant cells, or animal cells. Examples include bacillus thuringiensis (Bt) protein (from bacteria), and Pyrethrum (made from dried flower heads of certain chrysanthemum varieties), both used to control insects.

Bt crops: Crops that are genetically engineered to carry a gene from the soil bacterium *Bacillus thuringiensis* (Bt). The bacterium produces proteins that are toxic to some pests but non-toxic to humans and other mammals. Crops containing the Bt gene can produce this toxin, thereby providing protection for the plant. Bt corn and Bt cotton are examples of commercially available Bt crops.

Cell: The structural and functional unit of all living organisms. Most organisms consist of more than one cell, which become specialized into functions to enable the whole organism to function properly. Cells contain DNA and many other elements to enable the cell to function.

Chromosome: The self-replicating genetic structure of cells, containing genes that determine inheritance of traits. Chemically, each chromosome is composed of proteins and a long molecule of DNA.

Clone: A genetic replica of an organism created without sexual reproduction.

Conventional Breeding is the process by which scientists and farmers improve crops by selecting plants with desirable traits and crossing them with other plants to combine those traits over multiple generations. It relies on natural reproductive processes—such as hand-pollinating plants with complementary characteristics—and can take many years to produce stable new varieties with improved yield, disease resistance, or other useful features

CryIA: A protein derived from the bacterium *Bacillus thuringiensis* that is toxic to some insects when ingested. This bacterium occurs widely in nature and has been used for decades as an insecticide.

Deregulation: The process or act of removing government restrictions or regulations on planting, import, and/or export. Plant commodities are deregulated upon the government receiving and evaluating scientific research demonstrating food, feed, and human safety and minimal impact on the environment.

DNA (deoxyribonucleic acid): The chemical substance from which genes are made. DNA is a long, double-stranded helical molecule made up of nucleotides which are themselves composed of sugars, phosphates, and derivatives of the four bases adenine (A), guanine (G), cytosine (C), and thymine (T). The sequence order of the four bases in the DNA strands determines the genetic information contained.

Gene: The fundamental physical and functional unit of heredity. A gene is typically a specific segment of a chromosome and encodes a specific functional product (such as a protein or RNA molecule).

Gene expression: The result of the activity of a gene or genes that influence the biochemistry and physiology of an organism and may change its outward appearance.

Gene flow: The movement of genes from one individual or population to another genetically compatible individual or population.

Gene mapping: Determining the relative physical locations of genes on a chromosome. Useful for plant and animal breeding.

Gene (DNA) sequencing: Determining the exact sequence of nucleotide bases in a strand of DNA to better understand the function of a gene.

Genetic engineering: The process of manipulating an organism's DNA (and thereby genes) by introducing, eliminating, or rearranging specific genes using the methods of modern molecular biology, particularly those techniques referred to as recombinant DNA techniques.

Genetically engineered organism (GEO): An organism produced through genetic engineering.

Genetic modification: The production of heritable improvements in plants or animals for specific uses, via either genetic engineering or other more traditional methods. Some countries other than the United States use this term to refer specifically to genetic engineering.

Genetically modified organism (GMO): An organism produced through genetic modification.

Genetics: The study of the patterns of inheritance of specific traits.

Genome: All the genetic material in all the chromosomes of a particular organism.

Genome editing is a broader term that refers to tools that allow scientists to make targeted changes anywhere across an organism's entire set of DNA (its genome). This is different from older GMO methods,

which typically involved adding a gene from a different species, like inserting a new sentence from another book. With gene and genome editing, scientists are usually working with the plant's own genetic material, just more precisely and efficiently than traditional breeding allows.

Genomics: The mapping and sequencing of genetic material in the DNA of a particular organism as well as the use of that information to better understand what genes do, how they are controlled, how they work together, and what their physical locations are on the chromosome.

Genomic library: A collection of biomolecules made from DNA fragments of a genome that represent the genetic information of an organism that can be propagated and then systematically screened for particular properties. The DNA may be derived from the genomic DNA of an organism or from DNA copies made from messenger RNA molecules.

Genotype: The genetic identity of an individual. Genotype often is evident by outward characteristics but may also be reflected in more subtle biochemical ways not visually evident.

Glyphosate: An herbicide used to kill weeds, such as those that compete with commercial crops. It is often associated with the trade name Roundup®. Farmers favor glyphosate for its ability to control many types of weeds and its low toxicity compared with other herbicides.

Herbicide: A class of crop protection and specialty chemicals used to control weeds on farms and in forests, as well as in non-agricultural applications such as golf courses, public properties, and home lawns.

Herbicide-tolerant crops: Crops developed to survive application(s) of certain herbicides by the incorporation of certain gene(s) either through genetic engineering or traditional breeding methods. The genes allow the herbicides to be applied to the crop to provide effective weed control without damaging the crop itself.

Hybrid: The offspring of any cross between two organisms of different genotypes.

Insecticide: A class of crop protection and specialty chemicals used to control insects on farms and forests, as well as non-agricultural applications such as residential lawn care, golf courses, and public properties.

Insect-resistant crops: Plants with the ability to withstand, deter or repel insects and thereby prevent them from feeding on the plant. The traits (genes) determining resistance may be selected by plant breeders through cross-pollination with other varieties of this crop or through the introduction of novel genes such as Bt genes through genetic engineering.

Insect-resistance management: A strategy for delaying the development of pesticide resistance by maintaining a portion of the pest population in a refuge that is free from contact with the insecticide. For Bt crops this allows the insects feeding on the Bt toxin to mate with insects not exposed to the toxin produced in the plants.

Molecular biology: The study of the structure and function of proteins and nucleic acids in biological systems.

Mutation: Any heritable change in DNA structure or sequence. The identification and incorporation of useful mutations has been essential for traditional crop breeding.

Nanotechnology: A science that involves the design and application of structures, devices, and systems on an extremely small scale, called the nanoscale; that is, billionths of a meter, or about 1-millionth the size of a pinhead. Potential applications related to food include food packaging and processing to improve food safety and quality, and better nutrient and ingredient profiles to improve health.

No tillage/no-till farming: Planting crops directly into the residue of the previous year's crop. In addition to amplifying the benefits of conservation tillage, leaving crop residue untouched also helps to sequester carbon, a greenhouse gas, in the soil.

Organic: A food production system that follows specific standards for crop production, animal raising, soil quality, and processing.

Pesticide: A broad class of crop protection products, including four major types: insecticides used to control insects; herbicides used to control weeds; rodenticides used to control rodents; and fungicides used to control mold, mildew, and fungi. Both farmers and consumers use pesticides in the home or yard to control termites and roaches, clean mold from shower curtains, stave off crab grass on the lawn, kill fleas and ticks on pets, disinfect swimming pools, etc.

Plant breeding: The use of cross-pollination, selection, and certain other techniques involving crossing plants to produce varieties with desired characteristics (traits) that can be passed on to future plant generations.

Plant-incorporated protectants (PIPs): Pesticidal substances introduced into plants by genetic engineering that are produced and used by the plant to protect it from pests. The protein toxins of Bt are often used as PIPs in the formation of Bt crops. This is a terminology adopted by the EPA (U.S. Environmental Protection Agency) and is only applied in the context of regulating biopesticides.

Plant pests: Organisms that may directly or indirectly cause disease, spoilage, or damage to plants, plant parts or processed plant materials. Common examples include certain insects, mites, nematodes, fungi, molds, viruses, and bacteria.

Protein: A molecule composed of one or more chains of amino acids in a specific order. Proteins are required for the structure, function, and regulation of the body's cells, tissues, and organs, and each protein has a unique function.

Recombinant DNA (rDNA) technology: Procedures used to join DNA segments in a cell-free system (e.g. in a test tube outside living cells or organisms). Under appropriate conditions, a recombinant DNA molecule can be introduced into a cell and copy itself (replicate), either as an independent entity (autonomously) or as an integral part of a cellular chromosome.

Regenerative agriculture: A holistic approach to farming that focuses on building healthy, resilient, fertile soil to increase biodiversity, sequester carbon, and improve water cycles and ecosystems. Regenerative practices aim to slow climate change by keeping carbon in the soil, rather than releasing it into the atmosphere. Carbon-rich soil nourishes plants, retains water during a drought, and resists erosion.

Ribonucleic Acid (RNA): A chemical substance made up of nucleotides compound of sugars, phosphates, and derivatives of the four bases adenine (A), guanine (G), cytosine (C), and uracil (U). RNAs function in cells as messengers of information from DNA that are translated into protein or as molecules that have certain structural or catalytic functions in the synthesis of proteins. RNA is also the carrier of genetic information for certain viruses. RNAs may be single or double stranded.

Selective breeding: Making deliberate crosses or matings of organisms so the offspring will have desired characteristics derived from one or both parents.

Stacked traits: The biotechnology process by which more than one gene can be transferred, resulting in a plant with two or more transgenic traits. Usually, a result of the crossing of two transgenic plants with different transgenes.

Staple crops: The most common crops in people's diets, such as rice, wheat, and maize (corn), which provide 60% of the world's food energy intake.

Transgene: A gene from one organism inserted into another organism by recombinant DNA techniques.

Transgenic organism: An organism resulting from the insertion of genetic material from another organism using recombinant DNA techniques.

Variety: A subdivision of a species for taxonomic classification also referred to as a 'cultivar.' A variety is a group of individual plants that is uniform, stable, and distinct genetically from other groups of individuals in the same species.

Virus: A simple, non-cellular parasite that can reproduce only inside living cells of other organisms. Viruses cause a large variety of significant diseases in plants, animals, and humans.

Virus-resistant crops: Plants with the ability to withstand plant viral diseases. Developed through traditional breeding or through genetic engineering (e.g., papaya ringspot virus-resistant papaya).

Vector: 1. A type of DNA element, such as a plasmid, or the genome of a bacteriophage, or virus, that is self-replicating and that can be used to transfer DNA segments into target cells. 2. An insect or other organism that provides a means of dispersal for a disease or parasite.

Weed: A plant that is growing in an undesired area and can overtake other plants by overcrowding, depleting soil nutrients and moisture that would otherwise be available to preferred plants or crops.

Yield: The amount of an agricultural crop, such as a grain, fruit, or vegetable, produced in a season. It can be measured in pounds or bushels per acre, or kilograms or metric tons per hectare.



REFERENCES

1. Sánchez MA, Parrott WA. Characterization of scientific studies usually cited as evidence of adverse effects of GM food/feed. *Plant Biotechnol J*. 2017 Oct;15(10):1227-1234. doi: 10.1111/pbi.12798. Epub 2017 Aug 16. PMID: 28710840; PMCID: PMC5595713.
2. National Academies of Sciences, Engineering, and Medicine. 2016. *Genetically Engineered Crops: Experiences and Prospects*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/23395>.
3. Smyth SJ. The human health benefits from GM crops. *Plant Biotechnol J*. 2020 Apr;18(4):887-888. doi: 10.1111/pbi.13261. Epub 2019 Oct 2. PMID: 31544299; PMCID: PMC7061863.
4. Brookes, G., & Barfoot, P. (2018). Environmental impacts of genetically modified (GM) crop use 1996-2016: Impacts on pesticide use and carbon emissions. *GM Crops & Food*, 9(3), 109–139. <https://doi.org/10.1080/21645698.2018.1476792>.
5. United States Department of Agriculture (USDA) Agricultural Marketing Service. Bioengineered Disclosure. Accessed September 20, 2025. <https://www.ams.usda.gov/rules-regulations/be>.
6. Omprakash A, Loitongbam B, Bairwa S.K., Chandra K. (2021). Gene stacking: Approach of genetic engineering. *Internat. J. agric. Sci.*, 17 (AAEBSSD): 326-330, DOI:10.15740/HAS/IJAS/17-AAEBSSD/326-330.
7. USDA AMS. Bioengineered Disclosure. Accessed September 20, 2025. <https://www.ams.usda.gov/rules-regulations/be>.
8. Tachikawa M, Matsuo M. Global regulatory trends of genome editing technology in agriculture and food. *Breed Sci*. 2024 Mar;74(1):3-10. doi: 10.1270/jsbbs.23046. Epub 2024 Feb 22. PMID: 39246438; PMCID: PMC11375430.
9. Klümper W, Qaim M. A Meta-Analysis of the Impacts of Genetically Modified Crops. *PLoS ONE* 2014; 9(11): e111629. <https://doi.org/10.1371/journal.pone.0111629>.
10. Brookes G, Barfoot P. GM crop technology use 1996-2018: farm income and production impacts. *GM Crops Food*. 2020;11(4), 242–261. <https://doi.org/10.1080/21645698.2020.1779574>
11. Littman A, Patel M, de Paula Uchoa R, van der Pluijm P. The economic and environmental benefits of advanced biotechnology. McKinsey Sustainability. March 11, 2025. <https://www.mckinsey.com/capabilities/sustainability/our-insights/sustainability-blog/the-economic-and-environmental-benefits-of-advanced-biotechnology>.
12. McFadden B, Lusk J, Taheripour F, et.al. Gains foregone by going GMO free: potential impacts on consumers, the environment, and agricultural producers. CAST Commentary. November 2021. <https://cast-science.org/wp-content/uploads/2024/08/QTA2021-2-GMO-Free-1.pdf>.
13. American Society of Human Genetics. Public Attitudes Toward Genetics & Genomics Research. January 2020. <https://www.ashg.org/wp-content/uploads/2020/01/2020-Public-Views-Genetics-Literature-Review.pdf>.
14. Paarlberg R. A dubious success: the NGO campaign against GMOs. *GM Crops Food*. 2014;5(3):223-228. doi:10.4161/21645698.2014.952204.
15. Girish HV, Murali M, Hemanth Kumar NK, Brijesh Singh S, Jagannath S, Sudarshana MS. Chapter 9 - GM Crops as a Food Security Solution. Editor(s): Pardeep Singh, Anwasha Borthakur, Aditya Abha Singh, Ajay Kumar, Kshitij K. Singh, *Pol Iss Gen Mod Crops*. Academic Press, 2021, Pages 189-199, ISBN 9780128207802. <https://doi.org/10.1016/B978-0-12-820780-2.00009-1>.

16. Hirschi KD. Genetically Modified Plants: Nutritious, Sustainable, yet Underrated. *J Nutr.* 2020;150(10):2628-2634. doi:10.1093/jn/nxaa220.
17. Brookes G. Genetically Modified (GM) Crop Use 1996-2020: Environmental Impacts Associated with Pesticide Use Change. *GM Crops Food.* 2022;13(1):262-289. doi:10.1080/21645698.2022.2118497.
18. Smyth S J, Phillips PWB, & Castle D. An assessment of the linkages between GM crop biotechnology and climate change mitigation. *GM Crops Food.* 2024; 15(1), 150–169. <https://doi.org/10.1080/21645698.2024.2335701>.
19. Kovak E, Blaustein-Rejto D, Qaim M. Genetically modified crops support climate change mitigation, *Trends Plant Sci.* Vol. 27, Issue 7, 2022, Pages 627-629, ISSN 1360-1385. <https://doi.org/10.1016/j.tplants.2022.01.004>.
20. Ahmed A, Hoddinott JF, Abedin N, Hossain NZ. Economic and health impacts of genetically modified eggplant: Results from a randomized controlled trial of Bt brinjal in Bangladesh. 2019. IFPRI Discussion Paper 1866. Washington, DC: International Food Policy Research Institute (IFPRI). <https://hdl.handle.net/10568/146827>.
21. Sharma P, Singh SP, Iqbal HMN, Parra-Saldivar R, Varjani S, Tong YW. Genetic modifications associated with sustainability aspects for sustainable developments. *Bioeng.* 2022;13(4), 9509–9521. <https://doi.org/10.1080/21655979.2022.2061146>.
22. HudsonAlpha Institute for Biotechnology. The Genetics of the Impossible Burger. Accessed September 22, 2025. <https://www.hudsonalpha.org>.
23. USDA Food Safety and Inspection Service (FSIS). Human food made with cultured animal cells. Accessed September 22, 2025. <https://www.fsis.usda.gov>.
24. Abdul Aziz M, Brini F, Rouached H, Masmoudi K. Genetically engineered crops for sustainably enhanced food production systems. *Front Plant Sci.* 2022;13:1027828. Published 2022 November 8. doi:10.3389/fpls.2022.1027828.
25. Sharma R, Yadav A, Lata, C. et al. Role of biotechnology for shelf-life extension and quality improvement of perishable fruits and vegetables: a comprehensive review. *Food Sci Biotechnol* 34, 3487–3506 (2025). <https://doi.org/10.1007/s10068-025-01858-3>.
26. Vaschetto L. Biotechnology and the development of hypoallergenic agriculture. AZO Life Sciences. Accessed September 20, 2025. <https://www.azolifesciences.com>.
27. USDA. Biotechnology FAQs. Accessed September 20, 2025. <https://www.usda.gov>.
28. Ferguson JN, Schmuker P, Dmitrieva A, et al. Reducing stomatal density by expression of a synthetic epidermal patterning factor increases leaf intrinsic water use efficiency and reduces plant water use in a C₄ crop, *J Exp Bot.* Vol. 75, Issue 21, 15 November 2024, Pages 6823–6836, <https://doi.org/10.1093/jxb/erae289>.
29. Fujs T, Kashiwase H. Strains on freshwater resources; the impact of food production on water consumption. *World Bank Blogs.* August 23, 2023. Accessed September 20, 2025. <https://blogs.worldbank.org>.
30. Ritchie H. How much of global greenhouse gas emissions come from food? March 18, 2021. OurWorldinData.org. <https://ourworldindata.org/greenhouse-gas-emissions-food>.
31. Brookes G. Genetically modified (GM) crop use 1996-2020: impacts on carbon emissions. *GM Crops Food.* 2022;13(1):242-261. doi:10.1080/21645698.2022.2118495.
32. Kapoor P. et al. Biotechnology for advancing regenerative agriculture: opportunities and challenges. *Regen Ag Sust Food Sys.* Springer, Singapore. https://doi.org/10.1007/978-981-97-6691-8_14.
33. Van Aken B. Transgenic plants for phytoremediation: helping nature to clean up environmental pollution. *Trends Biotech.* Vol. 26, Issue 5, 2008, Pages 225-227, ISSN 0167-7799, <https://doi.org/10.1016/j.tibtech.2008.02.001>.
34. Tepper K, King J, Manuneehi Cholan P. et al. Methylmercury demethylation and volatilization by animals expressing microbial enzymes. *Nat Commun.* 16, 1117 (2025). <https://doi.org/10.1038/s41467-025-56145-w>.

35. Oak Ridge National Laboratory. New approach 'stacks' genes for faster plant transformation. <https://www.ornl.gov/news/new-approach-stacks-genes-faster-plant-transformation>. Accessed September 20, 2025. <https://www.ornl.gov/news/new-approach-stacks-genes-faster-plant-transformation>.
36. Gheysen G, Kreuze JF. The genome of cultivated sweet potato contains *Agrobacterium* T-DNAs with expressed genes: An example of a naturally transgenic food crop. *Proc Natl Acad Sci USA*. 2015 May 5; 112(18):5844-9. doi: 10.1073/pnas.1419685112. Epub 2015 Apr 20. PMID: 25902487; PMCID: PMC4426443.
37. USAID Feed the Future. Insect-resistant eggplant partnership. Cornell University and U.S. Government's Hunger and Food Security Initiative. Accessed September 20, 2025. <https://bteggplant.cornell.edu/bt-eggplant>.
38. Hawaii Papaya Industry Association. The rainbow story. Accessed September 20, 2025. <https://www2.hawaii.edu/~doisteph/Papaya/rainbow.html#:~:text=Commercialized%20in%201998%2C%20the%20Rainbow,the%20papaya%20ringspot%20virus%20invasion>.
39. Mmbando GS. Exploring the capacity of modern biotechnology to enhance climate smart crop production in Africa. *Discov Agric* 3, 48 (2025). <https://doi.org/10.1007/s44279-025-00198-4>.
40. Uga Y, Sugimoto K, Ogawa S, et al. Control of root system architecture by DEEPER ROOTING 1 increases rice yield under drought conditions. *Nat Genet*. 2013 Sep;45(9):1097-102. doi:10.1038/ng.2725. Epub 2013 Aug 4. PMID: 23913002.
41. Wang J, Zhu R, Meng Q, et al. A natural variation in OsDSK2a modulates plant growth and salt tolerance through phosphorylation by SnRK1A in rice. *Plant Biotechnol. J*. 2024; 22: 1881-1896. <https://doi.org/10.1111/pbi.14308>.
42. Yang R, Ma Y, Yang, Z, et al. Knockdown of β -conglycinin q' and q subunits alters seed protein composition and improves salt tolerance in soybean. *Plant J*. 2024; 120: 1488-1507. <https://doi.org/10.1111/tpj.17062>.
43. Fiaz S, Wang X, Khan SA, et al. Novel plant breeding techniques to advance nitrogen use efficiency in rice: A review. *GM Crops Food*. 2021;12(2):627-646. doi:10.1080/21645698.2021.1921545.
44. Van Zeebroeck M, Van linden V, Ramon H, et al. Impact damage of apples during transport and handling. *Postharvest Biol. Technol*. Vol. 45, Issue 2, 2007, Pages 157-167, ISSN 0925-5214. <https://doi.org/10.1016/j.postharvbio.2007.01.015>.
45. Klümper W, Qaim M. A meta-analysis of the impacts of genetically modified crops. *PLoS One*. 2014;9(11):e111629. Published 2014 Nov 3. doi:10.1371/journal.pone.0111629.
46. Kyndt T, Quispe D, Zhai, H, et al. The genome of cultivated sweet potato contains *Agrobacterium* T-DNAs with expressed genes: An example of a naturally transgenic food crop. *Proc. Natl. Acad. Sci. U.S.A.* 2015; 112 (18) 5844-5849. <https://doi.org/10.1073/pnas.1419685112>.
47. European Commission. GMO legislation. Accessed September 20, 2025. <https://food.ec.europa.eu/plants/genetically-modified-organisms/gmo-legislation>.
48. European Commission. Fact Sheet: Questions and Answers on EU's policies on GMOs. April 21, 2015. Accessed September 20, 2025. https://ec.europa.eu/commission/presscorner/detail/en/memo_15_4778.
49. U.S. Food & Drug Administration. How GMOs are regulated in the United States. Updated March 5, 2024. Accessed September 20, 2025. <https://www.fda.gov/food/agricultural-biotechnology/how-gmos-are-regulated-united-states>.
50. ISAAA. Pocket k no. 51: coexistence of biotech and non-biotech crops. Accessed September 20, 2025. <https://www.isaaa.org/resources/publications/pocketk/51/default.asp>.
51. Dively GP, Venugopal PD, Bean D, et al. Regional pest suppression associated with widespread Bt maize adoption benefits vegetable growers. *Proc. Natl. Acad. Sci. U.S.A.* 2018; 115 (13) 3320-3325. <https://doi.org/10.1073/pnas.1720692115>.
52. U.S. Food & Drug Administration. GMO crops, animal food, and beyond. Updated March 5, 2024. Accessed September 20, 2025. <https://www.fda.gov/food/agricultural-biotechnology/gmo-crops-animal-food-and-beyond>.

53. Fuglie K, MacDonal JM. USDA Economic Research Service. August 28, 2023. Accessed September 20, 2025. <https://www.ers.usda.gov/amber-waves>.
54. The Royal Society. What can be done to prevent cross breeding of GM crops? Accessed September 20, 2025. <https://royalsociety.org/news-resources/projects/gm-plants>.
55. ISAAA. Countries approving GM crop cultivation 1996-2024. Accessed September 20, 2025. <https://www.isaaa.org/resources/infographics/countriesapprovinggmcropcultivation/default.asp>.
56. ISAAA. Pocket k no. 16: biotech crop highlights in 2019. Accessed September 20, 2025. <https://www.isaaa.org/resources/publications/pocketk/16>.
57. U.S. Environmental Protection Agency. Food and Pesticides. Accessed September 20, 2025. <https://www.epa.gov/safepestcontrol/food-and-pesticides>.
58. National Academies of Sciences, Engineering, and Medicine. Do foods made with GMOs pose special health risks? Accessed September 20, 2025. <https://www.nationalacademies.org/based-on-science>.
59. European Academies Science Advisory Council. Planting the future: opportunities and challenges for using crop genetic improvement technologies for sustainable agriculture. EASAC policy report 21. June 2013. ISBN: 978-3-8047-3181-3. <https://easac.eu>.
60. Fedorhoff N. GM crops: facts and myths. February 26, 2013. *World Economic Forum*. <https://www.weforum.org/stories/2013/02/gm-crops-facts-and-myths>.
61. AMA Policy Finder. Bioengineered (Genetically Engineered) Crops and Foods H-480.958. 2022. <https://policysearch.amaassn.org/policyfinder/detail/biotechnology?uri=%2FAMADoc%2FHOD.xml-0-4359.xml>.
62. American Association for the Advancement of Science. Statement by the AAAS board of directors on labeling of genetically modified foods. October 20, 2012. https://www.aaas.org/sites/default/files/AAAS_GM_statement.pdf.
63. Scott P, Thomson J, Grzywacz D, et al. Genetic modification for disease resistance: a position paper. *Food Sec.* 8, 865–870 (2016). <https://doi.org/10.1007/s12571-016-0591-9>.
64. Position of the American Dietetic Association: Total Diet Approach to Communicating Food and Nutrition Information. *J Aca Diet Assoc.* Vol. 107, Issue 7, 1224 – 1232. [https://www.jandonline.org/article/S0002-8223\(05\)02109-7/abstract](https://www.jandonline.org/article/S0002-8223(05)02109-7/abstract).
65. Foundation for Biotechnology Awareness and Education. Are there health hazards for the consumer from eating genetically modified foods? 2006. http://www.fbae.org/2009/FBAE/website/special-topics_are_there_health_hazards.html
66. Government of Canada. Novel foods: safety of genetically modified foods. Modified July 24, 2024. <https://www.canada.ca/en/health-canada/services/food-nutrition/genetically-modified-foods-other-novel-foods/safety.html>.
67. World Health Organization. Food, genetically modified. May 1, 2024. Accessed September 20, 2025. <https://www.who.int/news-room/questions-and-answers/item/FAQ-genetically-modified-foods>.
68. Kubiak A, Wolna-Maruwka A, Niewiadomska A, Pilarska AA. The Problem of Weed Infestation of Agricultural Plantations vs. the Assumptions of the European Biodiversity Strategy. *Agronomy*. 2022; 12(8):1808. <https://doi.org/10.3390/agronomy12081808>.
69. International Food Information Council. Public Perceptions of Pesticides & Produce Consumption. April 2024. https://ific.org/wp-content/uploads/2025/04/2024-IFIC-Spotlight-Survey_Pesticides-Produce-Consumption.pdf.
70. Ag Daily. List of organic pesticides approved by the USDA. Accessed September 20, 2025. <https://www.agdaily.com/technology/the-list-of-pesticides-approved-for-organic-production/>.

71. U.S. Environmental Protection Agency. Food and Pesticides. Accessed September 20, 2025. <https://www.epa.gov/safepestcontrol/food-and-pesticides>.
72. Environmental Working Group. The Dirty Dozen. Accessed September 20, 2025. <https://www.ewg.org/foodnews/dirty-dozen.php>.
73. USDA Agricultural Marketing Service. Pesticide Data Program. (2021) Accessed September 20, 2025. <https://www.safefruitsandveggies.com/wpcontent/uploads/2023/01/2021PDPAnnualSummary.pdf>.
74. U.S. Food & Drug Administration. Pesticide Residue Monitoring Program Questions and Answers. Accessed September 20, 2025. <https://www.fda.gov/food/pesticides/pesticide-residue-monitoring-program-questions-andanswers#:~:text=The%20EPA%20also%20provides%20a,in%20the%20average%20U.S.%20diet>.
75. Brookes G, Barfoot P. Environmental impacts of genetically modified (GM) crop use 1996-2016: Impacts on pesticide use and carbon emissions. *GM Crops & Food*. 2018 9(3), 109–139. <https://doi.org/10.1080/21645698.2018.1476792>.
76. Romeis J, Naranjo SE, Meissle M, Shelton, AM. Genetically engineered crops help support conservation biological control. *Biol Cont*, Vol. 130, 2019, Pages 136-154, ISSN 1049-9644. <https://doi.org/10.1016/j.biocontrol.2018.10.001>.
77. USDA Economic Research Service. Adoption of Genetically Engineered Crops in the United States-Recent Trends in GE adoption. Updated January 4, 2025. Accessed September 20, 2025. <https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-united-states/recent-trends-in-ge-adoption>.
78. Kathage J, Qaim M. Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India. *Proc Natl Acad Sci U S A*. 2012;109(29):11652-11656. doi:10.1073/pnas.1203647109
79. Regulatory Horizons Council. Report on Genetic Technologies. Updated July 2022. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1089198/regulatory_horizons_council_report_on_genetic_technologies_july_2022.pdf.
80. USDA Economic Research Service. Adoption of Genetically Engineered Crops in the United States-Recent Trends in GE adoption. Updated January 4, 2025. Accessed September 20, 2025. <https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-united-states/recent-trends-in-ge-adoption>.
81. Pecenka JR, Ingwell LL, Foster RE, Krupke CH, Kaplan I. IPM reduces insecticide applications by 95% while maintaining or enhancing crop yields through wild pollinator conservation. *Proc Natl Acad Sci U S A*. 2021;118(44):e2108429118. doi:10.1073/pnas.2108429118.
82. Ayilara MS, Adeleke BS, Akinola SA, et al. Biopesticides as a promising alternative to synthetic pesticides: A case for microbial pesticides, phytopesticides, and nanobiopesticides. *Front Microbiol*. 2023;14:1040901. Published 2023 Feb 16. doi:10.3389/fmicb.2023.1040901.
83. Tadesse Mawcha K, Malinga L, Muir D, Ge J, Ndolo D. Recent Advances in Biopesticide Research and Development with a Focus on Microbials. *F1000Res*. 2025;13:1071. Published 2025 Mar 11. doi:10.12688/f1000research.154392.5.
84. Wang D, Saleh NB, Byro A. et al. Nano-enabled pesticides for sustainable agriculture and global food security. *Nat. Nanotechnol*. 17, 347–360 (2022). <https://doi.org/10.1038/s41565-022-01082-8>.
85. Getahun S, Kefale H, Gelaye Y. Application of Precision Agriculture Technologies for Sustainable Crop Production and Environmental Sustainability: A Systematic Review. *ScientificWorldJournal*. 2024;2024:2126734. Published 2024 Oct 9. doi:10.1155/2024/2126734.



International
Food Information
Council

The International Food Information Council (IFIC) sincerely thanks Regan Bailey, PhD, MPH, RD, Professor of Biomedical Sciences and Social Medicine and Director of Institute for Connecting Nutrition and Health at Florida State University; Connie Diekman, M.Ed., RD, CSSD, LD, FADA, FAND; Sarah Davidson Evanga, PhD, Founding Executive Director, Cornell Alliance for Science at Cornell University (former); and Annette Maggi, MS, RDN, LD, FAND for their expert review of this document.

[ific.org](https://www.ific.org)

