Genetically modified crops

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Genetically modified crops (**GMCs**, **GM crops**, or **biotech crops**) are plants used in agriculture, the DNA of which has been modified using genetic engineering techniques. In most cases, the aim is to introduce a new trait to the plant which does not occur naturally in the species. Examples in food crops include resistance to certain pests, diseases, or environmental conditions, reduction of spoilage, or resistance to chemical treatments (e.g. resistance to a herbicide), or improving the nutrient profile of the crop. Examples in non-food crops include production of pharmaceutical agents, biofuels, and other industrially useful goods, as well as for bioremediation.[1]

Farmers have widely adopted GM technology. Between 1996 and 2015, the total surface area of land cultivated with GM crops increased by a factor of 100, from 17,000 km^2 (4.2 million acres) to 1,797,000 km^2 (444 million acres).[2] 10% of the world's arable land was planted with GM crops in 2010.[3] In the US, by 2014, 94% of the planted area of soybeans, 96% of cotton and 93% of corn were genetically modified varieties.[4] Use of GM crops expanded rapidly in developing countries, with about 18 million farmers growing 54% of worldwide GM crops by 2013.[1] A 2014 meta-analysis concluded that GM technology adoption had reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%.[5] This reduction in pesticide use has been ecologically beneficial, but benefits may be reduced by overuse.[6] Yield gains and pesticide reductions are larger for insect-resistant crops than for herbicide-tolerant crops. Yield and profit gains are higher in developing countries than in developed countries.[5]

There is a scientific consensus[7][8][9][10] that currently available food derived from GM crops poses no greater risk to human health than conventional food,[11][12][13][14][15] but that each GM food needs to be tested on a case-by-case basis before introduction.[16][17][18] Nonetheless, members of the public are much less likely than scientists to perceive GM foods as safe.[19][20][21][22] The legal and regulatory status of GM foods varies by country, with some nations banning or restricting them, and others permitting them with widely differing degrees of regulation.[23][24][25][26]

However, opponents have objected to GM crops on several grounds, including environmental concerns, whether food produced from GM crops is safe, whether GM crops are needed to address the world's food needs, and concerns raised by the fact these organisms are subject to intellectual property law.

Contents

Gene transfer in nature and traditional agriculture

DNA transfers naturally between organisms.[27] Several natural mechanisms allow gene flow across species. These occur in nature on a large scale – for example, it is one mechanism for the development of antibiotic resistance in bacteria.[28] This is facilitated by transposons, retrotransposons, proviruses and other mobile genetic elements that naturally translocate DNA to new loci in a genome.[29][30] Movement occurs over an evolutionary time scale.[31][32][33]

The introduction of foreign germplasm into crops has been achieved by traditional crop breeders by overcoming species barriers. A hybrid cereal grain was created in 1875, by crossing wheat and rye.[34] Since then important traits including dwarfing genes and rust resistance have been introduced.[35] Plant tissue culture and deliberate mutations have enabled humans to alter the makeup of plant genomes.[36][37]

History

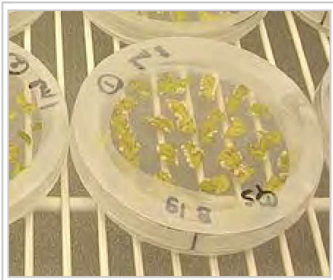
The first genetically modified crop plant was produced in 1982, an antibiotic-resistant tobacco plant.[38] The first field trials occurred in France and the USA in 1986, when tobacco plants were engineered for herbicide resistance.[39] In 1987, Plant Genetic Systems (Ghent, Belgium), founded by Marc Van Montagu and Jeff Schell, was the first company to genetically engineer insect-resistant (tobacco) plants by incorporating genes that produced insecticidal proteins from *Bacillus thuringiensis* (Bt).[40]

The People's Republic of China was the first country to allow commercialized transgenic plants, introducing a virus-resistant tobacco in 1992,[41] which was withdrawn in 1997.[42]:3 The first genetically modified crop approved for sale in the U.S., in 1994, was the *FlavrSavr* tomato. It had a longer shelf life, because it took longer to soften after ripening.[43] In 1994, the European Union approved tobacco engineered to be resistant to the herbicide bromoxynil, making it the first commercially genetically engineered crop marketed in Europe.[44]

In 1995, Bt Potato was approved by the US Environmental Protection Agency, making it the country's first pesticide producing crop.[45] In 1995 canola with modified oil composition (Calgene), Bt maize (Ciba-Geigy), bromoxynil-resistant cotton (Calgene), Bt cotton (Monsanto), glyphosate-resistant soybeans (Monsanto), virus-resistant squash (Asgrow), and additional delayed ripening tomatoes (DNAP, Zeneca/Peto, and Monsanto) were approved.[39] As of mid-1996, a total of 35 approvals had been granted to commercially grow 8 transgenic crops and one flower crop (carnation), with 8 different traits in 6 countries plus the EU.[39] In 2000, Vitamin A-enriched golden rice was developed, though as of 2016 it was not yet in commercial production. In 2013 the leaders of the three research teams that first applied genetic engineering to crops, Robert Fraley, Marc Van Montagu and Mary-Dell Chilton were awarded the World Food Prize for improving the "quality, quantity or availability" of food in the world.[46]

Methods

Genetically engineered crops have genes added or removed using genetic engineering techniques,[47] originally including gene guns, electroporation, microinjection and agrobacterium. More recently, CRISPR and TALEN offered much more precise and convenient editing techniques.



Plants (*Solanum chacoense*) being transformed using agrobacterium

Gene guns (also known as biolistics) "shoot" (direct high energy particles or radiations against[48]) target genes into plant cells. It is the most common method. DNA is bound to tiny particles of gold or tungsten which are subsequently shot into plant tissue or single plant cells under high pressure. The accelerated particles penetrate both the cell wall and membranes. The DNA separates from the metal and is integrated into plant DNA inside the nucleus. This method has been applied successfully for many cultivated crops, especially monocots like wheat or maize, for which transformation using *Agrobacterium tumefaciens* has been less successful.[49] The major disadvantage of this procedure is that serious damage can be done to the cellular tissue.

Agrobacterium tumefaciens-mediated transformation is another common technique. Agrobacteria are natural plant parasites, and their natural ability to transfer genes provides another engineering method. To create a suitable environment for themselves, these Agrobacteria insert their genes into plant hosts, resulting in a proliferation of modified plant cells near the soil level (crown gall). The genetic information for tumour growth is encoded on a mobile, circular DNA fragment (plasmid). When *Agrobacterium* infects a plant, it transfers this T-DNA to a random site in the plant genome. When used in genetic engineering the bacterial T-DNA is removed from the bacterial plasmid and replaced with the desired foreign gene. The bacterium is a vector, enabling transportation of foreign genes into plants. This method works especially well for dicotyledonous plants like potatoes, tomatoes, and tobacco. Agrobacteria infection is less successful in crops like wheat and maize.

Electroporation is used when the plant tissue does not contain cell walls. In this technique, "DNA enters the plant cells through miniature pores which are temporarily caused by electric pulses."

Microinjection directly injects the gene into the DNA.[50]

Plant scientists, backed by results of modern comprehensive profiling of crop composition, point out that crops modified using GM techniques are less likely to have unintended changes than are conventionally bred crops.[51][52]

In research tobacco and *Arabidopsis thaliana* are the most frequently modified plants, due to well-developed transformation methods, easy propagation and well studied genomes.[53][54] They serve as model organisms for other plant species.

Introducing new genes into plants requires a promoter specific to the area where the gene is to be expressed. For instance, to express a gene only in rice grains and not in leaves, an endosperm-specific promoter is used. The codons of the gene must be optimized for the organism due to codon usage bias.

Types of modifications

Transgenic

Transgenic maize containing a gene from the bacteria *Bacillus thuringiensis*

Transgenic plants have genes inserted into them that are derived from another species. The inserted genes can come from species within the same kingdom (plant to plant) or between kingdoms (for example, bacteria to plant). In many cases the inserted DNA has to be modified slightly in order to correctly and efficiently express in the host organism. Transgenic plants are used to express proteins like the cry toxins from *B. thuringiensis*, herbicide resistant genes, antibodies[55] and antigens for vaccinations[56] A study led by the European Food Safety Authority (EFSA) found also viral genes in transgenic plants.[57]

Transgenic carrots have been used to produce the drug Taliglucerase alfa which is used to treat Gaucher's disease.[58] In the laboratory, transgenic plants have been modified to increase photosynthesis (currently about 2% at most plants versus the theoretic potential of 9–10%).[59] This is possible by changing the rubisco enzyme (i.e. changing C3 plants into C4 plants[60]), by placing the rubisco in a carboxysome, by adding CO_2 pumps in the cell wall,[61][62] by changing the leaf form/size.[63][64][65][66] Plants have been engineered to exhibit bioluminescence that may become a sustainable alternative to electric lighting.[67]

Cisgenic

Cisgenic plants are made using genes found within the same species or a closely related one, where conventional plant breeding can occur. Some breeders and scientists argue that cisgenic modification is useful for plants that are difficult to crossbreed by conventional means (such as potatoes), and that plants in the cisgenic category should not require the same regulatory scrutiny as transgenics.[68]

Subgenic

Genetically modified plants can also be developed using gene knockdown or gene knockout to alter the genetic makeup of a plant without incorporating genes from other plants. In 2014, Chinese researcher Gao Caixia filed patents on the creation of a strain of wheat that is resistant to powdery mildew. The strain lacks genes that encode proteins that repress defenses against the mildew. The researchers deleted all three copies of the genes from wheat's hexaploid genome. Gao used the TALENs and CRISPR gene editing tools without adding or changing any other genes. No field trials were immediately planned.[69][70] The CRISPR technique has also been used to modify white button mushrooms (*Agaricus bisporus*).[71]

Economics

GM food's economic value to farmers is one of its major benefits, including in developing nations.[72][73][74] A 2010 study found that Bt corn provided economic benefits of $6.9 billion over the previous 14 years in five Midwestern states. The majority ($4.3 billion) accrued to farmers producing non-Bt corn. This was attributed to European corn borer populations reduced by exposure to Bt corn, leaving fewer to attack conventional corn nearby.[75][76] Agriculture economists calculated that "world surplus [increased by] $240.3 million for 1996. Of this total, the largest share (59%) went to U.S. farmers. Seed company Monsanto received the next largest share (21%), followed by US consumers (9%), the rest of the world (6%), and the germplasm supplier, Delta & Pine Land Company of Mississippi (5%)."[77]

According to the International Service for the Acquisition of Agri-biotech Applications (ISAAA), in 2014 approximately 18 million farmers grew biotech crops in 28 countries; about 94% of the farmers were resource-poor in developing countries. 53% of the global biotech crop area of 181.5 million hectares was grown in 20 developing countries.[78] PG Economics comprehensive 2012 study concluded that GM crops increased farm incomes worldwide by $14 billion in 2010, with over half this total going to farmers in developing countries.[79]

Critics challenged the claimed benefits to farmers over the prevalence of biased observers and by the absence of randomized controlled trials. The main Bt crop grown by small farmers in developing countries is cotton. A 2006 review of Bt cotton findings by agricultural economists concluded, "the overall balance sheet, though promising, is mixed. Economic returns are highly variable over years, farm type, and geographical location".[80]

In 2013 the European Academies Science Advisory Council (EASAC) asked the EU to allow the development of agricultural GM technologies to enable more sustainable agriculture, by employing fewer land, water and nutrient resources. EASAC also criticizes the EU's "timeconsuming and expensive regulatory framework" and said that the EU had fallen behind in the adoption of GM technologies.[81]

Participants in agriculture business markets include seed companies, agrochemical companies, distributors, farmers, grain elevators and universities that develop new crops/traits and whose agricultural extensions advise farmers on best practices. According to a 2012 review based on data from the late 1990s and early 2000s, much of the GM crop grown each year is used for livestock feed and increased demand for meat leads to increased demand for GM feedcrops.[82] Feed grain usage as a percentage of total crop production is 70% for corn and more than 90% of oil seed meals such as soybeans. About 65 million metric tons of GM corn grains and about 70 million metric tons of soybean meals derived from GM soybean become feed.[82]

In 2014 the global value of biotech seed was US$15.7 billion; US$11.3 billion (72%) was in industrial countries and US$4.4 billion (28%) was in the developing countries.[78] In 2009, Monsanto had $7.3 billion in sales of seeds and from licensing its technology; DuPont, through its Pioneer subsidiary, was the next biggest company in that market.[83] As of 2009, the overall Roundup line of products including the GM seeds represented about 50% of Monsanto's business.[84]

Some patents on GM traits have expired, allowing the legal development of generic strains that include these traits. For example, generic glyphosate-tolerant GM soybean is now available. Another impact is that traits developed by one vendor can be added to another vendor's proprietary strains, potentially increasing product choice and competition.[85] The patent on the first type of *Roundup Ready* crop that Monsanto produced (soybeans) expired in 2014[86] and the first harvest of off-patent soybeans occurs in the spring of 2015.[87] Monsanto has broadly licensed the patent to other seed companies that include the glyphosate resistance trait in their seed products.[88] About 150 companies have licensed the technology,[89] including Syngenta[90] and DuPont Pioneer.[91]

Yield

In 2014, the largest review yet concluded that GM crops' effects on farming were positive. The meta-analysis considered all published English-language examinations of the agronomic and economic impacts between 1995 and March 2014 for three major GM crops: soybean, maize, and cotton. The study found that herbicide-tolerant crops have lower production costs, while for insect-resistant crops the reduced pesticide use was offset by higher seed prices, leaving overall production costs about the same.[5][92]

Yields increased 9% for herbicide tolerance and 25% for insect resistant varieties. Farmers who adopted GM crops made 69% higher profits than those who did not. The review found that GM crops help farmers in developing countries, increasing yields by 14 percentage points.[92]

The researchers considered some studies that were not peer-reviewed, and a few that did not report sample sizes. They attempted to correct for publication bias, by considering sources beyond academic journals. The large data set allowed the study to control for potentially confounding variables such as fertiliser use. Separately, they concluded that the funding source did not influence study results.[92]

Traits

GM crops grown today, or under development, have been modified with various traits. These traits include improved shelf life, disease resistance, stress resistance, herbicide resistance, pest resistance, production of useful goods such as biofuel or drugs, and ability to absorb toxins and for use in bioremediation of pollution.

Recently, research and development has been targeted to enhancement of crops that are locally important in developing countries, such as insect-resistant cowpea for Africa[93] and insect-resistant brinjal (eggplant).[94]

Lifetime

The first genetically modified crop approved for sale in the U.S. was the *FlavrSavr* tomato, which had a longer shelf life.[43] It is no longer on the market.

In November 2014, the USDA approved a GM potato that prevents bruising.[95][96]

In February 2015 Arctic Apples were approved by the USDA,[97] becoming the first genetically modified apple approved for US sale.[98] Gene silencing was used to reduce the expression of polyphenol oxidase (PPO), thus preventing enzymatic browning of the fruit after it has been sliced open. The trait was added to Granny Smith and Golden Delicious varieties.[97][99] The trait includes a bacterial antibiotic resistance gene that provides resistance to the antibiotic kanamycin. The genetic engineering involved cultivation in the presence of kanamycin, which allowed only resistant cultivars to survive. Humans consuming apples do not acquire kanamycin resistance, per arcticapple.com.[100] The FDA approved the apples in March 2015.[101]

Nutrition

Edible oils

Some GM soybeans offer improved oil profiles for processing or healthier eating.[102][103] Camelina sativa has been modified to produce plants that accumulate high levels of oils similar to fish oils.[104][105]

Vitamin enrichment

Golden rice, developed by the International Rice Research Institute (IRRI), provides greater amounts of Vitamin A targeted at reducing Vitamin A deficiency.[106][107] As of January 2016, golden rice has not yet been grown commercially in any country.[108]

Researchers vitamin-enriched corn derived from South African white corn variety M37W, producing a 169-fold increase in Vitamin A, 6-fold increase in Vitamin C and doubled concentrations of folate.[109] Modified Cavendish bananas express 10-fold the amount of Vitamin A as unmodified varieties.[110]

Toxin reduction

A genetically modified cassava under development offers lower cyanogen glucosides and enhanced protein and other nutrients (called BioCassava).[111]

In November 2014, the USDA approved a potato, developed by J.R. Simplot Company, that prevents bruising and produces less acrylamide when fried. The modifications prevent natural, harmful proteins from being made via RNA interference.[95][96] They do not employ genes from non-potato species. The trait was added to the Russet Burbank, Ranger Russet and Atlantic varieties.[95]

Stress resistance

Plants engineered to tolerate non-biological stressors such as drought,[95][96][112][113] frost,[114][115] high soil salinity,[116][117] and nitrogen starvation[118] were in development. In 2011, Monsanto's DroughtGard maize became the first drought-resistant GM crop to receive US marketing approval.[119]

Herbicides

Glyphosate

As of 1999 the most prevalent GM trait was glyphosate-resistance.[120] Glyphosate, (the active ingredient in Roundup and other herbicide products) kills plants by interfering with the shikimate pathway in plants, which is essential for the synthesis of the aromatic amino acids phenylalanine, tyrosine and tryptophan. The shikimate pathway is not present in animals, which instead obtain aromatic amino acids from their diet. More specifically, glyphosate inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS).

This trait was developed because the herbicides used on grain and grass crops at the time were highly toxic and not effective against narrow-leaved weeds. Thus, developing crops that could withstand spraying with glyphosate would both reduce environmental and health risks, and give an agricultural edge to the farmer.[120]

Some micro-organisms have a version of EPSPS that is resistant to glyphosate inhibition. One of these was isolated from an *Agrobacterium* strain CP4 (CP4 EPSPS) that was resistant to glyphosate.[121][122] The CP4 EPSPS gene was engineered for plant expression by fusing the 5' end of the gene to a chloroplast transit peptide derived from the petunia EPSPS. This transit peptide was used because it had shown previously an ability to deliver bacterial EPSPS to the chloroplasts of other plants. This CP4 EPSPS gene was cloned and transfected into soybeans.

The plasmid used to move the gene into soybeans was PV-GMGTO4. It contained three bacterial genes, two CP4 EPSPS genes, and a gene encoding beta-glucuronidase (GUS) from *Escherichia coli* as a marker. The DNA was injected into the soybeans using the particle acceleration method. Soybean cultivar A54O3 was used for the transformation.

Bromoxynil

Tobacco plants have been engineered to be resistant to the herbicide bromoxynil.[44]

Glufosinate

Crops have been commercialized that are resistant to the herbicide glufosinate, as well.[123] Crops engineered for resistance to multiple herbicides to allow farmers to use a mixed group of two, three, or four different chemicals are under development to combat growing herbicide resistance.[124][125]

2,4-D

In October 2014 the US EPA registered Dow's Enlist Duo maize, which is genetically modified to be resistant to both glyphosate and 2,4-D, in six states.[126][127] Inserting a bacterial aryloxyalkanoate dioxygenase gene, *aad1* makes the corn resistant to 2,4-D.[126][128] The USDA had approved maize and soybeans with the mutation in September 2014.[129]

Dicamba

Monsanto has requested approval for a stacked strain that is tolerant of both glyphosate and dicamba.[130]

Pest resistance

Insects

Tobacco, corn, rice and many other crops have been engineered to express genes encoding for insecticidal proteins from Bacillus thuringiensis (Bt).[45][131] Papaya, potatoes, and squash have been engineered to resist viral pathogens such as cucumber mosaic virus which, despite its name, infects a wide variety of plants.[132] The introduction of Bt crops during the period between 1996 and 2005 has been estimated to have reduced the total volume of insecticide active ingredient use in the United States by over 100 thousand tons. This represents a 19.4% reduction in insecticide use.[133]

In the late 1990s, a genetically modified potato that was resistant to the Colorado potato beetle was withdrawn because major buyers rejected it, fearing consumer opposition.[95]

Viruses

Virus resistant papaya were developed In response to a papaya ringspot virus (PRV) outbreak in Hawaii in the late 1990s. . They incorporate PRV DNA.[134][135] By 2010, 80% of Hawaiian papaya plants were genetically modified.[136][137]

Potatoes were engineered for resistance to potato leaf roll virus and Potato virus Y in 1998. Poor sales led to their market withdrawal after three years.[138]

Yellow squash that were resistant to at first two, then three viruses were developed, beginning in the 1990s. The viruses are watermelon, cucumber and zucchini/courgette yellow mosaic. Squash was the second GM crop to be approved by US regulators. The trait was later added to zucchini.[139]

Many strains of corn have been developed in recent years to combat the spread of Maize dwarf mosaic virus, a costly virus that causes stunted growth which is carried in Johnson grass and spread by aphid insect vectors. These strands are commercially available although the resistance is not standard among GM corn variants.[140]

By-products

Drugs

In 2012, the FDA approved the first plant-produced pharmaceutical, a treatment for Gaucher's Disease.[141] Tobacco plants have been modified to produce therapeutic antibodies.[142]

Biofuel

Algae is under development for use in biofuels.[143] Researchers in Singapore were working on GM jatropha for biofuel production.[144] Syngenta has USDA approval to market a maize trademarked Enogen that has been genetically modified to convert its starch to sugar for ethanol.[145] In 2013, the Flemish Institute for Biotechnology was investigating poplar trees genetically engineered to contain less lignin to ease conversion into ethanol.[146] Lignin is the critical limiting factor when using wood to make bio-ethanol because lignin limits the accessibility of cellulose microfibrils to depolymerization by enzymes.[147]

Materials

Companies and labs are working on plants that can be used to make bioplastics.[148] Potatoes that produce industrially useful starches have been developed as well.[149] Oilseed can be modified to produce fatty acids for detergents, substitute fuels and petrochemicals.

Bioremediation

Scientists at the University of York developed a weed (*Arabidopsis thaliana*) that contains genes from bacteria that could clean TNT and RDX-explosive soil contaminants in 2011.[150] 16 million hectares in the USA (1.5% of the total surface) are estimated to be contaminated with TNT and RDX. However *A. thaliana* was not tough enough for use on military test grounds.[151] Modifications in 2016 included switchgrass and bentgrass.[152]

Genetically modified plants have been used for bioremediation of contaminated soils. Mercury, selenium and organic pollutants such as polychlorinated biphenyls (PCBs).[151][153]

Marine environments are especially vulnerable since pollution such as oil spills are not containable. In addition to anthropogenic pollution, millions of tons of petroleum annually enter the marine environment from natural seepages. Despite its toxicity, a considerable fraction of petroleum oil entering marine systems is eliminated by the hydrocarbon-degrading activities of microbial communities. Particularly successful is a recently discovered group of specialists, the so-called hydrocarbonoclastic bacteria (HCCB) that may offer useful genes.[154]

Asexual reproduction

Crops such as maize reproduce sexually each year. This randomizes which genes get propagated to the next generation, meaning that desirable traits can be lost. To maintain a high-quality crop, some farmers purchase seeds every year. Typically, the seed company maintains two inbred varieties, and crosses them into a hybrid strain that is then sold. Related plants like sorghum and gamma grass are able to perform apomixis, a form of asexual reproduction that keeps the plant's DNA intact. This trait is apparently controlled by a single dominant gene, but traditional breeding has been unsuccessful in creating asexually-reproducing maize. Genetic engineering offers another route to this goal. Successful modification would allow farmers to replant harvested seeds that retain desirable traits, rather than relying on purchased seed.[155]

Crops

Herbicide tolerance

GMO	Use	Countries approved in	First approved [156]	Notes
Alfalfa	Animal feed[157]	USA	2005	Approval withdrawn in 2007[158] and then re-approved in 2011[159]
Canola	Cooking oil Margarine Emulsifiers in packaged foods[157]	Australia	2003	
		Canada	1995	
		USA	1995	
Cotton	Fiber Cottonseed oil Animal feed[157]	Argentina	2001	
		Australia	2002	
		Brazil	2008	
		Columbia	2004	
		Costa Rica	2008	
		Mexico	2000	
		Paraguay	2013	
		South Africa	2000	
		USA	1994	
Maize	Animal feed high-fructose corn syrup corn starch[157]	Argentina	1998	
		Brazil	2007	
		Canada	1996	
		Colombia	2007	
		Cuba	2011	
		European Union	1998	Grown in Portugal, Spain, Czech Republic, Slovakia and Romania[160]
		Honduras	2001	
		Paraguay	2012	
		Philippines	2002	
		South Africa	2002	
		USA	1995	
		Uruguay	2003	
Soybean	Animal feed Soybean oil[157]	Argentina	1996	
		Bolivia	2005	
		Brazil	1998	
		Canada	1995	
		Chile	2007	
		Costa Rica	2001	
		Mexico	1996	
		Paraguay	2004	
		South Africa	2001	
		USA	1993	
		Uruguay	1996	
Sugar Beet	Food[161]	Canada	2001	
		USA	1998	Commercialised 2007,[162] production blocked 2010, resumed 2011.[161]

Insect resistance

GMO	Use	Countries approved in	First approved[156]	Notes
Cotton	Fiber Cottonseed oil Animal feed[157]	Argentina	1998	
		Australia	2003	
		Brazil	2005	
		Burkina Faso	2009	
		China	1997	
		Colombia	2003	
		Costa Rica	2008	
		India	2002	Largest producer of Bt cotton[163]
		Mexico	1996	
		Myanmar	2006[N 1]	
		Pakistan	2010[N 1]	
		Paraguay	2007	
		South Africa	1997	
		Sudan	2012	
		USA	1995	
Eggplant	Food	Bangladesh	2013	12 ha planted on 120 farms in 2014[164]
Maize	Animal feed high-fructose corn syrup corn starch[157]	Argentina	1998	
		Brazil	2005	
		Columbia	2003	
		Mexico	1996	Centre of origin for maize[165]
		Paraguay	2007	
		Philippines	2002	
		South Africa	1997	
		Uruguay	2003	
		USA	1995	
Poplar	Tree	China	1998	543 ha of bt poplar planted in 2014[166]

Other modified traits

GMO	Use	Trait	Countries approved in	First approved[156]	Notes
Canola	Cooking oil Margarine Emulsifiers in packaged foods[157]	High laurate canola	Canada	1996	
Canola	Cooking oil Margarine Emulsifiers in packaged foods[157]	High laurate canola	USA	1994	
Canola	Cooking oil Margarine Emulsifiers in packaged foods[157]	Phytase production	USA	1998	
Carnation	Ornamental	Delayed senescence	Australia	1995	
Carnation	Ornamental	Delayed senescence	Norway	1998	
Carnation	Ornamental	Modified flower colour	Australia	1995	
Carnation	Ornamental	Modified flower colour	Columbia	2000	In 2014 4 ha were grown in greenhouses for export[167]
Carnation	Ornamental	Modified flower colour	European Union	1998	Two events expired 2008, another approved 2007
Carnation	Ornamental	Modified flower colour	Japan	2004	
Carnation	Ornamental	Modified flower colour	Malaysia	2012	For ornamental purposes
Carnation	Ornamental	Modified flower colour	Norway	1997	
Maize	Animal feed high-fructose corn syrup corn starch[157]	Increased lysine	Canada	2006	
Maize	Animal feed high-fructose corn syrup corn starch[157]	Increased lysine	USA	2006	
Maize	Animal feed high-fructose corn syrup corn starch[157]	Drought tolerance	Canada	2010	
Maize	Animal feed high-fructose corn syrup corn starch[157]	Drought tolerance	USA	2011	
Papaya	Food[157]	Virus resistance	China	2006	
Papaya	Food[157]	Virus resistance	USA	1996	Mostly grown in Hawaii[157]
Petunia	Ornamental	Modified flower colour	China	1997[168]	
Potato	Food[157]	Virus resistance	Canada	1999	
Potato	Food[157]	Virus resistance	USA	1997	
Potato	Industrial[169]	Modified starch	USA	2014	
Rose	Ornamental	Modified flower colour	Australia	2009	Surrendered renewal
Rose	Ornamental	Modified flower colour	Colombia	2010[N 2]	Greenhouse cultivation for export only.
Rose	Ornamental	Modified flower colour	Japan	2008	
Rose	Ornamental	Modified flower colour	USA	2011	
Soybean	Animal feed Soybean oil[157]	Increased oleic acid production	Argentina	2015	
Soybean	Animal feed Soybean oil[157]	Increased oleic acid production	Canada	2000	
Soybean	Animal feed Soybean oil[157]	Increased oleic acid production	USA	1997	
Soybean	Animal feed Soybean oil[157]	Stearidonic acid production	Canada	2011	
Soybean	Animal feed Soybean oil[157]	Stearidonic acid production	USA	2011	
Squash	Food[157]	Virus resistance	USA	1994	
Sugar Cane	Food	Drought tolerance	Indonesia	2013	Environmental certificate only
Tobacco	Cigarettes	Nicotine reduction	USA	2002	

Development

The number of USDA-approved field releases for testing grew from 4 in 1985 to 1,194 in 2002 and averaged around 800 per year thereafter. The number of sites per release and the number of gene constructs (ways that the gene of interest is packaged together with other elements) —have rapidly increased since 2005. Releases with agronomic properties (such as drought resistance) jumped from 1,043 in 2005 to 5,190 in

2013. As of September 2013, about 7,800 releases had been approved for corn, more than 2,200 for soybeans, more than 1,100 for cotton, and about 900 for potatoes. Releases were approved for herbicide tolerance (6,772 releases), insect resistance (4,809), product quality such as flavor or nutrition (4,896), agronomic properties like drought resistance (5,190), and virus/fungal resistance (2,616). The institutions with the most authorized field releases include Monsanto with 6,782, Pioneer/DuPont with 1,405, Syngenta with 565, and USDA's Agricultural Research Service with 370. As of September 2013 USDA had received proposals for releasing GM rice, squash, plum, rose, tobacco, flax and chicory.[170]

Farming practices

Resistance

Bt resistance

Constant exposure to a toxin creates evolutionary pressure for pests resistant to that toxin. Overreliance on glyphosate and a reduction in the diversity of weed management practices allowed the spread of glyphosate resistance in 14 weed species/biotypes in the US.[170]

One method of reducing resistance is the creation of refuges to allow nonresistant organisms to survive and maintain a susceptible population.

To reduce resistance to Bt crops, the 1996 commercialization of transgenic cotton and maize came with a management strategy to prevent insects from becoming resistant. Insect resistance management plans are mandatory for Bt crops. The aim is to encourage a large population of pests so that any (recessive) resistance genes are diluted within the population. Resistance lowers evolutionary fitness in the absence of the stressor (Bt). In refuges, non-resistant strains outcompete resistant ones.[171]

With sufficiently high levels of transgene expression, nearly all of the heterozygotes (S/s), i.e., the largest segment of the pest population carrying a resistance allele, will be killed before maturation, thus preventing transmission of the resistance gene to their progeny.[172] Refuges (i. e., fields of nontransgenic plants) adjacent to transgenic fields increases the likelihood that homozygous resistant (s/s) individuals and any surviving heterozygotes will mate with susceptible (S/S) individuals from the refuge, instead of with other individuals carrying the resistance allele. As a result, the resistance gene frequency in the population remains lower.

Complicating factors can affect the success of the high-dose/refuge strategy. For example, if the temperature is not ideal, thermal stress can lower Bt toxin production and leave the plant more susceptible. More importantly, reduced late-season expression has been documented, possibly resulting from DNA methylation of the promoter.[173] The success of the high-dose/refuge strategy has successfully maintained the value of Bt crops. This success has depended on factors independent of management strategy, including low initial resistance allele frequencies, fitness costs associated with resistance, and the abundance of non-Bt host plants outside the refuges.[174]

Companies that produce Bt seed are introducing strains with multiple Bt proteins. Monsanto did this with Bt cotton in India, where the product was rapidly adopted.[175] Monsanto has also; in an attempt to simplify the process of implementing refuges in fields to comply with Insect Resistance Management(IRM) policies and prevent irresponsible planting practices; begun marketing seed bags with a set proportion of refuge (non-transgenic) seeds mixed in with the Bt seeds being sold. Coined "Refuge-In-a-Bag" (RIB), this practice is intended to increase farmer compliance with refuge requirements and reduce additional labor needed at planting from having separate Bt and refuge seed bags on hand.[176] This strategy is likely to reduce the likelihood of Bt-resistance occurring for corn rootworm, but may increase the risk of resistance for lepidopteran corn pests, such as European corn borer. Increased concerns for resistance with seed mixtures include partially resistant larvae on a Bt plant being able to move to a susceptible plant to survive or cross pollination of refuge pollen on to Bt plants that can lower the amount of Bt expressed in kernels for ear feeding insects.[177][178]

Herbicide resistance

Best management practices (BMPs) to control weeds may help delay resistance. BMPs include applying multiple herbicides with different modes of action, rotating crops, planting weed-free seed, scouting fields routinely, cleaning equipment to reduce the transmission of weeds to other fields, and maintaining field borders.[170] The most widely planted GMOs are designed to tolerate herbicides. By 2006 some weed populations had evolved to tolerate some of the same herbicides. Palmer amaranth is a weed that competes with cotton. A native of the southwestern US, it traveled east and was first found resistant to glyphosate in 2006, less than 10 years after GM cotton was introduced.[179][180][181]

Plant protection

Farmers generally use less insecticide when they plant Bt-resistant crops. Insecticide use on corn farms declined from 0.21 pound per planted acre in 1995 to 0.02 pound in 2010. This is consistent with the decline in European corn borer populations as a direct result of Bt corn and cotton. The establishment of minimum refuge requirements helped delay the evolution of Bt resistance. However resistance appears to be developing to some Bt traits in some areas.[170]

Tillage

By leaving at least 30% of crop residue on the soil surface from harvest through planting, conservation tillage reduces soil erosion from wind and water, increases water retention, and reduces soil degradation as well as water and chemical runoff. In addition, conservation tillage reduces the carbon footprint of agriculture.[182] A 2014 review covering 12 states from 1996 to 2006, found that a 1% increase in herbicde-tolerant (HT) soybean adoption leads to a 0.21% increase in conservation tillage and a 0.3% decrease in quality-adjusted herbicide use.[182]

Regulation

The regulation of genetic engineering concerns the approaches taken by governments to assess and manage the risks associated with the development and release of genetically modified crops. There are differences in the regulation of GM crops between countries, with some of the most marked differences occurring between the USA and Europe. Regulation varies in a given country depending on the intended use of each product. For example, a crop not intended for food use is generally not reviewed by authorities responsible for food safety.[183][184]

Production

In 2013, GM crops were planted in 27 countries; 19 were developing countries and 8 were developed countries. 2013 was the second year in which developing countries grew a majority (54%) of the total GM harvest. 18 million farmers grew GM crops; around 90% were small-holding farmers in developing countries.[1]

Country	2013– GM planted area (million hectares)[185]	Biotech crops
USA	70.1	Maize, Soybean, Cotton, Canola, Sugarbeet, Alfalfa, Papaya, Squash
Brazil	40.3	Soybean, Maize, Cotton
Argentina	24.4	Soybean, Maize, Cotton
India	11.0	Cotton
Canada	10.8	Canola, Maize, Soybean, Sugarbeet
Total	175.2	----

The United States Department of Agriculture (USDA) reports every year on the total area of GMO varieties planted in the United States.[186][187] According to National Agricultural Statistics Service, the states published in these tables represent 81–86 percent of all corn planted area, 88–90 percent of all soybean planted area, and 81–93 percent of all upland cotton planted area (depending on the year).

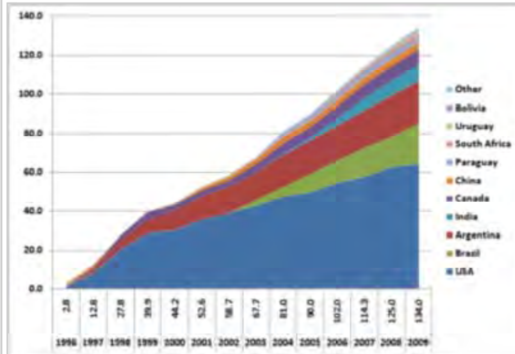
Global estimates are produced by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) and can be found in their annual reports, "Global Status of Commercialized Transgenic Crops".[1][188]

Farmers have widely adopted GM technology (see figure). Between 1996 and 2013, the total surface area of land cultivated with GM crops increased by a factor of 100, from 17,000 square kilometers (4,200,000 acres) to 1,750,000 km^2 (432 million acres).[1] 10% of the world's arable land was planted with GM crops in 2010.[3] As of 2011, 11 different transgenic crops were grown commercially on 395 million acres (160 million hectares) in 29 countries such as the USA, Brazil, Argentina, India, Canada, China, Paraguay, Pakistan, South Africa, Uruguay, Bolivia, Australia, Philippines, Myanmar, Burkina Faso, Mexico and Spain.[3] One of the key reasons for this widespread adoption is the perceived economic benefit the technology brings to farmers. For example, the system of planting glyphosate-resistant seed and then applying glyphosate once plants emerged provided farmers with the opportunity to dramatically increase the yield from a given plot of land, since this allowed them to plant rows closer together. Without it, farmers had to plant rows far enough apart to control post-emergent weeds with mechanical tillage.[189] Likewise, using Bt seeds means that farmers do not have to purchase insecticides, and then invest time, fuel, and equipment in applying them. However critics have disputed whether yields are higher and whether chemical use is less, with GM crops. See Genetically modified food controversies article for information.

In the US, by 2014, 94% of the planted area of soybeans, 96% of cotton and 93% of corn were genetically modified varieties.[4][190][191] Genetically modified soybeans carried herbicide-tolerant traits only, but maize and cotton carried both herbicide tolerance and insect protection traits (the latter largely Bt protein).[192] These constitute "input-traits" that are aimed to financially benefit the producers, but may have indirect environmental benefits and cost benefits to consumers. The Grocery Manufacturers of America estimated in 2003 that 70–75% of all processed foods in the U.S. contained a GM ingredient.[193]

Europe grows relatively few genetically engineered crops[194] with the exception of Spain, where one fifth of maize is genetically engineered,[195] and smaller amounts in five other countries.[196] The EU had a 'de facto' ban on the approval of new GM crops, from 1999 until 2004.[197][198] GM crops are now regulated by the EU.[199] In 2015, genetically engineered crops are banned in 38 countries worldwide, 19 of them in Europe.[200][201] Developing countries grew 54 percent of genetically engineered crops in 2013.[1]

In recent years GM crops expanded rapidly in developing countries. In 2013 approximately 18 million farmers grew 54% of worldwide GM crops in developing countries.[1] 2013's largest increase was in Brazil (403,000 km^2 versus 368,000 km^2 in 2012). GM cotton began growing in India in 2002, reaching 110,000 km^2 in 2013.[1]



Land area used for genetically modified crops by country (1996–2009), in millions of hectares. In 2011, the land area used was 160 million hectares, or 1.6 million square kilometers.[3]

According to the 2013 ISAAA brief: "...a total of 36 countries (35 + EU-28) have granted regulatory approvals for biotech crops for food and/or feed use and for environmental release or planting since 1994... a total of 2,833 regulatory approvals involving 27 GM crops and 336 GM events (NB: an "event" is a specific genetic modification in a specific species) have been issued by authorities, of which 1,321 are for food use (direct use or processing), 918 for feed use (direct use or processing) and 599 for environmental release or planting. Japan has the largest number (198), followed by the U.S.A. (165, not including "stacked" events), Canada (146), Mexico (131), South Korea (103), Australia (93), New Zealand (83), European Union (71 including approvals that have expired or under renewal process), Philippines (68), Taiwan (65), Colombia (59), China (55) and South Africa (52). Maize has the largest number (130 events in 27 countries), followed by cotton (49 events in 22 countries), potato (31 events in 10 countries), canola (30 events in 12 countries) and soybean (27 events in 26 countries).[1]

Controversy

GM foods are controversial and the subject of protests, vandalism, referenda, legislation, court action[202] and scientific disputes. The controversies involve consumers, biotechnology companies, governmental regulators, non-governmental organizations and scientists. The key areas are whether GM food should be labeled, the role of government regulators, the effect of GM crops on health and the environment, the effects of pesticide use and resistance, the impact on farmers, and their roles in feeding the world and energy production.

There is a scientific consensus[203][9][204][205] that currently available food derived from GM crops poses no greater risk to human health than conventional food,[206][207][208][14][15] but that each GM food needs to be tested on a case-by-case basis before introduction.[16][17][209] Nonetheless, members of the public are much less likely than scientists to perceive GM foods as safe.[19][20][21][210] The legal and regulatory status of GM foods varies by country, with some nations banning or restricting them, and others permitting them with widely differing degrees of regulation.[23][24][25][26]

No reports of ill effects have been documented in the human population from GM food.[211][212][213] Although GMO labeling is required in many countries, the United States Food and Drug Administration does not require labeling, nor does it recognize a distinction between approved GMO and non-GMO foods.[214]

Advocacy groups such as Center for Food Safety, Union of Concerned Scientists, Greenpeace and the World Wildlife Fund claim that risks related to GM food have not been adequately examined and managed, that GMOs are not sufficiently tested and should be labelled, and that regulatory authorities and scientific bodies are too closely tied to industry. Some studies have claimed that genetically modified crops can cause harm;[215][216] a 2016 review that reanalyzed the data from six of these studies found that their statistical methodologies were flawed and did not demonstrate harm, and said that conclusions about GMO crop safety should be drawn from "the totality of the evidence... instead of far-fetched evidence from single studies".[217]

See also

- Genetically modified food
- Genetically modified organisms
- Regulation of the release of genetic modified organisms

Notes

1. No official public documentation available
2. No public documents

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   "The literature about Biodiversity and the GE food/feed consumption has sometimes resulted in animated debate regarding the suitability of the experimental designs, the choice of the statistical methods or the public accessibility of data. Such debate, even if positive and part of the natural process of review by the scientific community, has frequently been distorted by the media and often used politically and inappropriately in anti-GE crops campaigns."

8. "State of Food and Agriculture 2003–2004. Agricultural Biotechnology: Meeting the Needs of the Poor. Health and environmental impacts of transgenic crops". Food and Agriculture Organization of the United Nations. Retrieved February 8, 2016. "Currently available transgenic crops and foods derived from them have been judged safe to eat and the methods used to test their safety have been deemed appropriate. These conclusions represent the consensus of the scientific evidence surveyed by the ICSU (2003) and they are consistent with the views of the World Health Organization (WHO, 2002). These foods have been assessed for increased risks to human health by several national regulatory authorities (inter alia, Argentina, Brazil, Canada, China, the United Kingdom and the United States) using their national food safety procedures (ICSU). To date no verifiable untoward toxic or nutritionally deleterious effects resulting from the consumption of foods derived from genetically modified crops have been discovered anywhere in the world (GM Science Review Panel). Many millions of people have consumed foods derived from GM plants - mainly maize, soybean and oilseed rape - without any observed adverse effects (ICSU)."
9. Ronald, Pamela (May 5, 2011). "Plant Genetics, Sustainable Agriculture and Global Food Security". *Genetics*. **188**: 11–20. doi:10.1534/genetics.111.128553. PMC 3120150. PMID 21546547. "There is broad scientific consensus that genetically engineered crops currently on the market are safe to eat. After 14 years of cultivation and a cumulative total of 2 billion acres planted, no adverse health or environmental effects have resulted from commercialization of genetically engineered crops (Board on Agriculture and Natural Resources, Committee on Environmental Impacts Associated with Commercialization of Transgenic Plants, National Research Council and Division on Earth and Life Studies 2002). Both the U.S. National Research Council and the Joint Research Centre (the European Union's scientific and technical research laboratory and an integral part of the European Commission) have concluded that there is a comprehensive body of knowledge that adequately addresses the food safety issue of genetically engineered crops (Committee on Identifying and Assessing Unintended Effects of Genetically Engineered Foods on Human Health and National Research Council 2004; European Commission Joint Research Centre 2008). These and other recent reports conclude that the processes of genetic engineering and conventional breeding are no different in terms of unintended consequences to human health and the environment (European Commission Directorate-General for Research and Innovation 2010)."

10. But see also:

Domingo, José L.; Bordonaba, Jordi Giné (2011). "A literature review on the safety assessment of genetically modified plants" (PDF). *Environment International*. **37**: 734–742. doi:10.1016/j.envint.2011.01.003. PMID 21296423. "In spite of this, the number of studies specifically focused on safety assessment of GM plants is still limited. However, it is important to remark that for the first time, a certain equilibrium in the number of research groups suggesting, on the basis of their studies, that a number of varieties of GM products (mainly maize and soybeans) are as safe and nutritious as the respective conventional non-GM plant, and those raising still serious concerns, was observed. Moreover, it is worth mentioning that most of the studies demonstrating that GM foods are as nutritional and safe as those obtained by conventional breeding, have been performed by biotechnology companies or associates, which are also responsible of commercializing these GM plants. Anyhow, this represents a notable advance in comparison with the lack of studies published in recent years in scientific journals by those companies."

Krimsky, Sheldon (2015). "An Illusory Consensus behind GMO Health Assessment" (PDF). *Science, Technology, & Human Values*. **40**: 1–32. doi:10.1177/0162243915598381. "I began this article with the testimonials from respected scientists that there is literally no scientific controversy over the health effects of GMOs. My investigation into the scientific literature tells another story."

And contrast:

Panchin, Alexander Y.; Tuzhikov, Alexander I. (January 14, 2016). "Published GMO studies find no evidence of harm when corrected for multiple comparisons". *Critical Reviews in Biotechnology*: 1–5. doi:10.3109/07388551.2015.1130684. ISSN 0738-8551. PMID 26767435. "Here, we show that a number of articles some of which have strongly and negatively influenced the public opinion on GM crops and even provoked political actions, such as GMO embargo, share common flaws in the statistical evaluation of the data. Having accounted for these flaws, we conclude that the data presented in these articles does not provide any substantial evidence of GMO harm."

"The presented articles suggesting possible harm of GMOs received high public attention. However, despite their claims, they actually weaken the evidence for the harm and lack of substantial equivalency of studied GMOs. We emphasize that with over 1783 published articles on GMOs over the last 10 years it is expected that some of them should have reported undesired differences between GMOs and conventional crops even if no such differences exist in reality."

and

Yang, Y.T.; Chen, B. (2016). "Governing GMOs in the USA: science, law and public health". *Journal of the Science of Food and Agriculture*. **96**: 1851–1855. doi:10.1002/jsfa.7523. PMID 26536836. "It is therefore not surprising that efforts to require labeling and to ban GMOs have been a growing political issue in the USA *(citing Domingo and Bordonaba, 2011)*."

"Overall, a broad scientific consensus holds that currently marketed GM food poses no greater risk than conventional food... Major national and international science and medical associations have stated that no adverse human health effects related to GMO food have been reported or substantiated in peer-reviewed literature to date."

"Despite various concerns, today, the American Association for the Advancement of Science, the World Health Organization, and many independent international science organizations agree that GMOs are just as safe as other foods. Compared with conventional breeding techniques, genetic engineering is far more precise and, in most cases, less likely to create an unexpected outcome."

11. "Statement by the AAAS Board of Directors On Labeling of Genetically Modified Foods" (PDF). American Association for the Advancement of Science. October 20, 2012. Retrieved February 8, 2016. "The EU, for example, has invested more than €300 million in research on the biosafety of GMOs. Its recent report states: "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." 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."

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"REPORT 2 OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH (A-12): Labeling of Bioengineered Foods" (PDF). American Medical Association. 2012. Retrieved March 19, 2016. "Bioengineered foods have been consumed for close to 20 years, and during that time, no overt consequences on human health have been reported and/or substantiated in the peer-reviewed literature."

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"GM foods currently available on the international market have passed safety assessments and are not likely to present risks for human health. In addition, no effects on human health have been shown as a result of the consumption of such foods by the general population in the countries where they have been approved. Continuous application of safety assessments based on the Codex Alimentarius principles and, where appropriate, adequate post market monitoring, should form the basis for ensuring the safety of GM foods."

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"When seeking to optimise the balance between benefits and risks, it is prudent to err on the side of caution and, above all, learn from accumulating knowledge and experience. Any new technology such as genetic modification must be examined for possible benefits and risks to human health and the environment. As with all novel foods, safety assessments in relation to GM foods must be made on a case-by-case basis."

"Members of the GM jury project were briefed on various aspects of genetic modification by a diverse group of acknowledged experts in the relevant subjects. The GM jury reached the conclusion that the sale of GM foods currently available should be halted and the moratorium on commercial growth of GM crops should be continued. These conclusions were based on the precautionary principle and lack of evidence of any benefit. The Jury expressed concern over the impact of GM crops on farming, the environment, food safety and other potential health effects."

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    "The literature about Biodiversity and the GE food/feed consumption has sometimes resulted in animated debate regarding the suitability of the experimental designs, the choice of the statistical methods or the public accessibility of data. Such debate, even if positive and part of the natural process of review by the scientific community, has frequently been distorted by the media and often used politically and inappropriately in anti-GE crops campaigns."

204. "State of Food and Agriculture 2003–2004. Agricultural Biotechnology: Meeting the Needs of the Poor. Health and environmental impacts of transgenic crops". Food and Agriculture Organization of the United Nations. Retrieved February 8, 2016. "Currently available transgenic crops and foods derived from them have been judged safe to eat and the methods used to test their safety have been deemed appropriate. These conclusions represent the consensus of the scientific evidence surveyed by the ICSU (2003) and they are consistent with the views of the World Health Organization (WHO, 2002). These foods have been assessed for increased risks to human health by several national regulatory authorities (inter alia, Argentina, Brazil, Canada, China, the United Kingdom and the United States) using their national food safety procedures (ICSU). To date no verifiable untoward toxic or nutritionally deleterious effects resulting from the consumption of foods derived from genetically modified crops have been discovered anywhere in the world (GM Science Review Panel). Many millions of people have consumed foods derived from GM plants - mainly maize, soybean and oilseed rape - without any observed adverse effects (ICSU)."

205. But see also:

Domingo, José L.; Bordonaba, Jordi Giné (2011). "A literature review on the safety assessment of genetically modified plants" (PDF). *Environment International*. **37**: 734–742. doi:10.1016/j.envint.2011.01.003. PMID 21296423. "In spite of this, the number of studies specifically focused on safety assessment of GM plants is still limited. However, it is important to remark that for the first time, a certain equilibrium in the number of research groups suggesting, on the basis of their studies, that a number of varieties of GM products (mainly maize and soybeans) are as safe and nutritious as the respective conventional non-GM plant, and those raising still serious concerns, was observed. Moreover, it is worth mentioning that most of the studies demonstrating that GM foods are as nutritional and safe as those obtained by conventional breeding, have been performed by biotechnology companies or associates, which are also responsible of commercializing these GM plants. Anyhow, this represents a notable advance in comparison with the lack of studies published in recent years in scientific journals by those companies."

Krimsky, Sheldon (2015). "An Illusory Consensus behind GMO Health Assessment" (PDF). *Science, Technology, & Human Values*. **40**: 1–32. doi:10.1177/0162243915598381. "I began this article with the testimonials from respected scientists that there is literally no scientific controversy over the health effects of GMOs. My investigation into the scientific literature tells another story."

And contrast:

Panchin, Alexander Y.; Tuzhikov, Alexander I. (January 14, 2016). "Published GMO studies find no evidence of harm when corrected for multiple comparisons". *Critical Reviews in Biotechnology*: 1–5. doi:10.3109/07388551.2015.1130684. ISSN 0738-8551. PMID 26767435. "Here, we show that a number of articles some of which have strongly and negatively influenced the public opinion on GM crops and even provoked political actions, such as GMO embargo, share common flaws in the statistical evaluation of the data. Having accounted for these flaws, we conclude that the data presented in these articles does not provide any substantial evidence of GMO harm."

"The presented articles suggesting possible harm of GMOs received high public attention. However, despite their claims, they actually weaken the evidence for the harm and lack of substantial equivalency of studied GMOs. We emphasize that with over 1783 published articles on GMOs over the last 10 years it is expected that some of them should have reported undesired differences between GMOs and conventional crops even if no such differences exist in reality."

and

Yang, Y.T.; Chen, B. (2016). "Governing GMOs in the USA: science, law and public health". *Journal of the Science of Food and Agriculture*. **96**: 1851–1855. doi:10.1002/jsfa.7523. PMID 26536836. "It is therefore not surprising that efforts to require labeling and to ban GMOs have been a growing political issue in the USA *(citing Domingo and Bordonaba, 2011)*."

"Overall, a broad scientific consensus holds that currently marketed GM food poses no greater risk than conventional food... Major national and international science and medical associations have stated that no adverse human health effects related to GMO food have been reported or substantiated in peer-reviewed literature to date."

"Despite various concerns, today, the American Association for the Advancement of Science, the World Health Organization, and many independent international science organizations agree that GMOs are just as safe as other foods. Compared with conventional breeding techniques, genetic engineering is far more precise and, in most cases, less likely to create an unexpected outcome."

206. "Statement by the AAAS Board of Directors On Labeling of Genetically Modified Foods" (PDF). American Association for the Advancement of Science. October 20, 2012. Retrieved February 8, 2016. "The EU, for example, has invested more than €300 million in research on the biosafety of GMOs. Its recent report states: "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." 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."

Pinholster, Ginger (October 25, 2012). "AAAS Board of Directors: Legally Mandating GM Food Labels Could "Mislead and Falsely Alarm Consumers" ". American Association for the Advancement of Science. Retrieved February 8, 2016.

207. "A decade of EU-funded GMO research (2001–2010)" (PDF). Directorate-General for Research and Innovation. Biotechnologies, Agriculture, Food. European Commission, European Union. 2010. doi:10.2777/97784. ISBN 978-92-79-16344-9. Retrieved February 8, 2016.

208. "AMA Report on Genetically Modified Crops and Foods (online summary)". American Medical Association. January 2001. Retrieved March 19, 2016. "A report issued by the scientific council of the American Medical Association (AMA) says that no long-term health effects have been detected from the use of transgenic crops and genetically modified foods, and that these foods are substantially equivalent to their conventional counterparts. *(from online summary prepared by ISAAA)*" "Crops and foods produced using recombinant DNA techniques have been available for fewer than 10 years and no long-term effects have been detected to date. These foods are substantially equivalent to their conventional counterparts. *(from original report by AMA: [3] (http://www.ama-assn.org/ama/pub/about-ama/our-people/ama-councils/council-science-public-health/reports/reports-topic.page?))*"

"REPORT 2 OF THE COUNCIL ON SCIENCE AND PUBLIC HEALTH (A-12): Labeling of Bioengineered Foods" (PDF). American Medical Association. 2012. Retrieved March 19, 2016. "Bioengineered foods have been consumed for close to 20 years, and during that time, no overt consequences on human health have been reported and/or substantiated in the peer-reviewed literature."

209. Some medical organizations, including the British Medical Association, advocate further caution based upon the precautionary principle:

"Genetically modified foods and health: a second interim statement" (PDF). British Medical Association. March 2004. Retrieved March 21, 2016. "In our view, the potential for GM foods to cause harmful health effects is very small and many of the concerns expressed apply with equal vigour to conventionally derived foods. However, safety concerns cannot, as yet, be dismissed completely on the basis of information currently available."

"When seeking to optimise the balance between benefits and risks, it is prudent to err on the side of caution and, above all, learn from accumulating knowledge and experience. Any new technology such as genetic modification must be examined for possible benefits and risks to human health and the environment. As with all novel foods, safety assessments in relation to GM foods must be made on a case-by-case basis."

"Members of the GM jury project were briefed on various aspects of genetic modification by a diverse group of acknowledged experts in the relevant subjects. The GM jury reached the conclusion that the sale of GM foods currently available should be halted and the moratorium on commercial growth of GM crops should be continued. These conclusions were based on the precautionary principle and lack of evidence of any benefit. The Jury expressed concern over the impact of GM crops on farming, the environment, food safety and other potential health effects."

"The Royal Society review (2002) concluded that the risks to human health associated with the use of specific viral DNA sequences in GM plants are negligible, and while calling for caution in the introduction of potential allergens into food crops, stressed the absence of evidence that commercially available GM foods cause clinical allergic manifestations. The BMA shares the view that that there is no robust evidence to prove that GM foods are unsafe but we endorse the call for further research and surveillance to provide convincing evidence of safety and benefit."

210. Scott, Sydney E.; Inbar, Yoel; Rozin, Paul (2016). "Evidence for Absolute Moral Opposition to Genetically Modified Food in the United States" (PDF). *Perspectives on Psychological Science*. **11** (3): 315–324. doi:10.1177/1745691615621275. PMID 27217243.
211. American Medical Association (2012). Report 2 of the Council on Science and Public Health: Labeling of Bioengineered Foods (https://web.archive.org/web/20120907023039/http://www.ama-assn.org/resources/doc/csaph/a12-csaph2-bioengineeredfoods.pdf)
212. United States Institute of Medicine and National Research Council (2004). Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects. National Academies Press. Free full-text (http://www.nap.edu/catalog.php?record_id=10977#toc). National Academies Press. See pp11ff on need for better standards and tools to evaluate GM food.
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214. Andrew Pollack for the New York Times. "An Entrepreneur Bankrolls a Genetically Engineered Salmon" (http://www.nytimes.com/2012/05/22/business/kakha-bendukidze-holds-fate-of-gene-engineered-salmon.html?pagewanted=all) Published: May 21, 2012. Accessed September 3, 2012
215. Domingo, José L.; Bordonaba, Jordi Giné (2011). "A literature review on the safety assessment of genetically modified plants" (PDF). *Environment International*. **37**: 734–742. doi:10.1016/j.envint.2011.01.003. PMID 21296423.
216. Krimsky, Sheldon (2015). "An Illusory Consensus behind GMO Health Assessment" (PDF). *Science, Technology, & Human Values*. **40**: 1–32. doi:10.1177/0162243915598381.
217. Panchin, Alexander Y.; Tuzhikov, Alexander I. (2016). "Published GMO studies find no evidence of harm when corrected for multiple comparisons". *Critical Reviews in Biotechnology*: 1–5. doi:10.3109/07388551.2015.1130684. PMID 26767435.

External links

- EU Register of authorised GMOs (http://ec.europa.eu/food/dyna/gm_register/index_en.cfm)
- Biotechnology Consultations on Food from GE Plant Varieties (http://www.accessdata.fda.gov/scripts/fdcc/?set=Biocon)
- Current & Previously Registered Section 3 PIP Registrations (http://www.epa.gov/pesticides/biopesticides/pips/pip_list.htm)

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