Genetically modified crops

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Genetically modified crops (**GMCs**, **GM crops**, or **biotech crops**) are plants, 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 include resistance to certain pests, diseases, or environmental conditions, or resistance to chemical treatments (e.g. resistance to a herbicide), or the production of a certain nutrient or pharmaceutical agent.

Genetic engineering techniques are much more precise[1] than mutagenesis (mutation breeding) where an organism is exposed to radiation or chemicals to create a non-specific but stable change. Other techniques by which humans modify plants include selective breeding; plant breeding, and somaclonal variation.

Critics have objected to GM crops per se on several grounds, including ecological concerns, and economic concerns raised by the fact these organisms are subject to intellectual property law. GM crops also are involved in controversies over GM food with respect to whether food produced from GM crops is safe and whether GM crops are needed to address the world's food needs.

Contents

Gene transfer in nature and traditional agriculture

Scientists first discovered that DNA naturally transfers between organisms in 1946.[2] It is now known that there are several natural mechanisms for flow of genes, or (horizontal gene transfer), and that these occur in nature on a large scale – for example, it is a major mechanism for antibiotic resistance in pathogenic bacteria, and it occurs between plant species.[3] This is facilitated by transposons, retrotransposons, proviruses and other mobile genetic elements that naturally translocate to new sites in a genome.[4][5] They often move to new species over an evolutionary time scale[6] and play a major role in dynamic changes to chromosomes during evolution.[7][8]

The introduction of foreign germplasm into crops has been achieved by traditional crop breeders by artificially overcoming fertility barriers. A hybrid cereal was created in 1875, by crossing wheat and rye.[9] Since then important traits have been introduced into wheat, including dwarfing genes and rust resistance.[10] Plant tissue culture and the induction of mutations have also enabled humans to artificially alter the makeup of plant genomes.[11][12]

History

Main article: History of genetic engineering

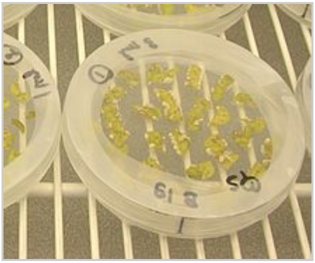
The first genetically modified plant was produced in 1982, using an antibiotic-resistant tobacco plant.[13] The first field trials of genetically engineered plants occurred in France and the USA in 1986, when tobacco plants were engineered to be resistant to herbicides.[14] In 1987, Plant Genetic Systems (Ghent, Belgium), founded by Marc Van Montagu and Jeff Schell, was the first company to develop genetically engineered (tobacco) plants with insect tolerance by expressing genes encoding for insecticidal proteins from Bacillus thuringiensis (Bt).[15] The People's Republic of China was the first country to allow commercialized transgenic plants, introducing a virus-resistant tobacco in 1992,[16] which was withdrawn from the market in China in 1997.[17]:3 The first genetically modified crop approved for sale in the U.S., in 1994, was the *FlavrSavr* tomato, which had a longer shelf life.[18] 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.[19] In 1995, Bt Potato was approved safe by the Environmental Protection Agency, making it the first pesticide producing crop to be approved in the USA.[20] The following transgenic crops also received marketing approval in the US in 1995: canola with modified oil composition (Calgene), *Bacillus thuringiensis* (Bt) corn/maize (Ciba-Geigy), cotton resistant to the herbicide bromoxynil (Calgene), Bt cotton (Monsanto), soybeans resistant to the herbicide glyphosate (Monsanto), virus-resistant squash (Asgrow), and additional delayed ripening tomatoes (DNAP, Zeneca/Peto, and Monsanto).[14] As of mid-1996, a total of 35 approvals had been granted to commercially grow 8 transgenic crops and one flower crop of carnations, with 8 different traits in 6 countries plus the EU.[14] In 2000, with the production of golden rice, scientists genetically modified food to increase its nutrient value for the first time.

Methods

Main article: Genetic engineering#Process

Genetically engineered plants are generated in a laboratory by altering their genetic makeup. This is usually done by adding one or more genes to a plant's genome using genetic engineering techniques.[21] Most genetically modified plants are generated by the biolistic method (particle gun) or by *Agrobacterium tumefaciens* mediated transformation. 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.[22][23]

In research tobacco and *Arabidopsis thaliana* are the most genetically modified plants, due to well developed transformation methods, easy propagation and well studied genomes.[24][25] They serve as model organisms for other plant species.



Plants (*Solanum chacoense*) being transformed using agrobacterium

In the biolistic 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 genome 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.[26] The major disadvantage of this procedure is that serious damage can be done to the cellular tissue.

Agrobacteria are natural plant parasites, and their natural ability to transfer genes provides another method for the development of genetically engineered plants. To create a suitable environment for themselves, these Agrobacteria insert their genes into plant hosts, resulting in a proliferation of 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.

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

The transgenic gene products should also be able to be denatured by heat so that they are destroyed during cooking.

Glyphosate resistance

One of the most famous kinds of GM crops are "Roundup Ready", or glyphosate-resistant. Glyphosate, (the active ingredient in Roundup) 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. More specifically, glyphosate inhibits the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS).

The shikimate pathway is not present in animals, which instead obtain aromatic amino acids from their diet.

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.[27][28] This CP4 EPSPS gene was cloned and transfected into soybeans. 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. 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. The expression of the GUS gene was used as the initial evidence of transformation. GUS expression was detected by a staining method in which the GUS enzyme converts a substrate into a blue precipitate. Those plants that showed GUS expression were then taken and sprayed with glyphosate, and their tolerance was tested over many generations.

Types of genetic engineering


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 *Bacillus thuringiensis*, herbicide resistant genes and antigens for vaccinations[29] Transgenic carrots have been used to produce the drug Taliglucerase alfa which is used to treat Gaucher's disease.[30] In the laboratory, transgenic plants have been modified to increase their photosynthesis (currently about 2% at most plants to the theoretic potential of 9–10%.[31] This is possible by changing the rubisco enzyme (i.e. changing C3 plants into C4 plants[32]), by placing the rubisco in a carboxysome, by adding CO_2 pumps in the cell wall,[33][34] by changing the leaf form/size.[35][36][37][38] Plants have been engineered to exhibit bioluminescence which might one day be a sustainable alternative to electric lighting.[39] Still other transgenic plants have been modified to fix ambient nitrogen in the plant.[40]

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 level of legal regulation as other genetically modified organisms.[41]

Business of GM Crops

The global value of biotech seed alone was US$13.2 billion in 2011, with the end product of commercial grain from biotech maize, soybean grain and cotton valued at approximately US$160 billion or more per year.[42]

Players in agriculture business markets include seed companies, agrochemical companies, distributors, farmers, grain elevators, and universities that develop new crops and whose agricultural extensions advise farmers on best practices.

The largest share of the GMO crops planted globally are from seed created by the United States firm Monsanto.[43] In 2007, Monsanto's trait technologies were planted on 246 million acres (1,000,000 km^2) throughout the world, a growth of 13 percent from 2006. However, patents on the first Monsanto products to enter the marketplace will begin to expire in 2014, democratizing Monsanto products. Syngenta, DuPont (especially via its Pioneer Hi-Bred subsidiary), and Bayer CropScience are also major players in the US and Europe. In addition, a 2007 report from the European Joint Research Commission predicts that by 2015, more than 40 per cent of new GM plants entering the global marketplace will have been developed in Asia.[44]

In the corn market, Monsanto's triple-stack corn—which combines Roundup Ready 2-weed control technology with YieldGard (Bt) Corn Borer and YieldGard Rootworm insect control—is the market leader in the United States. U.S. corn farmers planted more than 32 million acres (130,000 km^2) of triple-stack corn in 2008,[45] and it is estimated the product could be planted on 56 million acres (230,000 km^2) in 2014–2015. In the cotton market, Bollgard II with Roundup Ready Flex was planted on approximately 5 million acres (20,000 km^2) of U.S. cotton in 2008.[46]

According to the International Service for the Acquisition of Agri-Biotech Applications (ISAAA), in 2010 approximately 15 million farmers grew biotech crops in 29 countries. Over 90% of the farmers were resource-poor in developing countries.[47] 6.5 million farmers in China and 6.3 million small farmers in India grew biotech crops (mostly Bacillus thuringiensis cotton). The Philippines, South Africa (biotech cotton, maize, and soybeans often grown by subsistence women farmers) and another twelve developing countries also grew biotech crops in 2009.[48] 10 million more small and resource-poor farmers may have been secondary beneficiaries of Bt cotton in China.

According to a review published in 2012 and 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 will lead to increased demand for GM crops with which to feed them.[49] 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 are fed to livestock each year.[49]

Uses, actual and proposed

GM crops grown today, or under experimental development, have been modified with traits intended to provide benefit to farmers, consumers, or industry. 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, for use in bioremediation of pollution. Due to high regulatory and research costs, the majority of genetically modified crops in agriculture consist of commodity crops, such as soybean, maize, cotton and rapeseed.[50][51] Recently, some research and development has been targeted to enhancement of crops that are locally important in developing countries, such as insect-resistant cowpea for Africa[52] and insect-resistant brinjal (eggplant) for India.[53]

Improved shelf life

The first genetically modified crop approved for sale in the U.S. was the *FlavrSavr* tomato, which had a longer shelf life.[18] It is no longer on the market. As of 2012, an apple that has been genetically modified to resist browning, known as the Nonbrowning Arctic apple produced by Okanagan Specialty Fruits, is awaiting regulatory approval in the US and Canada. A gene in the fruit has been modified such that the apple produces less polyphenol oxidase, a chemical that manifests the browning.[54]

Improved nutrition

The GM oilseed crops on the market today offer improved oil profiles for processing or healthier edible oils.[55] The GM crops in development offer a wider array of environmental and consumer benefits such as nutritional enhancement and drought and stress tolerance. GM plants are being developed by both private companies and public research institutions such as CIMMYT, the International Maize and Wheat Improvement Centre.[56] Other examples include a genetically modified cassava with lower cyanogen glucosides and enhanced with protein and other nutrients,[57] while golden rice, developed by the International Rice Research Institute (IRRI), has been discussed as a possible cure for Vitamin A deficiency.[58] An international group of academics has generated a vitamin-enriched corn derived from South African white corn variety M37W with 169x increase in beta carotene, 6x the vitamin C and 2x folate – it is not in production anywhere, but proves that this can be done.[59]

Stress resistance

Plants engineered to tolerate non-biological stresses like drought,[60][61] frost,[62][63][64] high Soil salinity,[65] and nitrogen starvation[66] or with increased nutritional value (*e.g.* Golden rice[67]) were in development in 2011.

Herbicide resistance

Tobacco plants have been engineered to be resistant to the herbicide bromoxynil.[19] And many crops have created that are resistant to the herbicide glyphosate. As weeds have grown resistant to glyphosate and other herbicides used in concert with resistant GM crops, companies are developing crops engineered to become resistant to multiple herbicides to allow farmers to use a mixed group of two, three, or four different chemicals.[68]

Pathogen resistance – insects or viruses

Tobacco, corn, rice and many other crops, have been generated that express genes encoding for insecticidal proteins from Bacillus thuringiensis (Bt).[20][69] 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.

Production of biofuels

Algae, both hybrid and GM, is under development by several companies for the production of biofuels.[70] Jatropha has also been modified to improve its qualities for fuel product. Swiss-based Syngenta has received USDA approval to market a maize seed trademarked Enogen, which has been genetically modified to convert its own starch to sugar to speed the process of making ethanol for biofuel.[71] In 2013, the Flemish Institute for Biotechnology was investigating poplar trees genetically engineered to contain less lignin so that they would be more suitable for conversion into biofuels.[72] 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.[73]

Production of useful by-products

Drugs

Bananas have been developed, but are not in production, that produce human vaccines against infectious diseases such as Hepatitis B.[74] Tobacco plants have been developed and studied, but are not in production, that can produce therapeutic antibodies.[75]

Materials

Several companies and labs are working on engineering plants that can be used to make bioplastics.[76] Potatoes that produce more industrially useful starches have been developed as well.[77]

Bioremediation

Scientists at the University of York developed a weed (*Arabidopsis thaliana*) that contains genes from bacteria that can clean up TNT and RDX-explosive contaminants from the soil: It was hoped that this weed would eliminate this pollution.[78] 16 million hectares in the USA (1.5% of the total surface) are estimated to be contaminated with TNT and RDX. However the weed *Arabidopsis thaliana* was not tough enough to withstand the environment on military test grounds and research is continuing with the University of Washington to develop a tougher native grass.[79]

Genetically modified plants have also been used for bioremediation of contaminated soils. Mercury, selenium and organic pollutants such as polychlorinated biphenyls (PCBs), TNT and RDX explosive contaminants have been removed from soils by transgenic plants containing genes for bacterial enzymes.[79][80]

Extent of worldwide use of GM crops

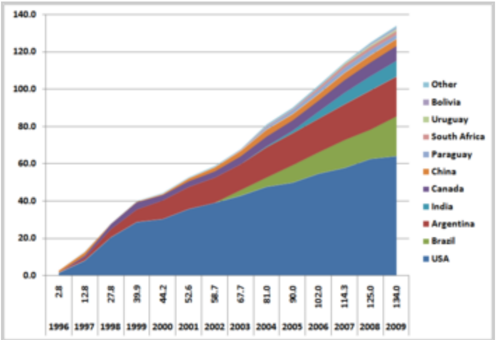
Country	2010– planted area (million hectares)[81]	2009 – Agriculture area (million hectares)[82]	Percentage of agriculture area with GM crops	Biotech crops
USA	66.8	403	16.56%	Soybean, Maize, Cotton, Canola, Squash, Papaya, Alfalfa, Sugarbeet
Brazil	25.4	265	9.60%	Soybean, Maize, Cotton
Argentina	22.9	141	16.30%	Soybean, Maize, Cotton
India	9.4	180	5.22%	Cotton
Canada	8.8	68	13.02%	Maize, Soybean, Canola, Sugarbeet
Rest of the world	14.7	3,883	0.38%	----

In the United States, the United States Department of Agriculture (USDA) reports on the total area of GMO varieties planted.[83] 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).

USDA does not collect data for global area. Estimates are produced by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) and can be found in the report, "Global Status of Commercialized Transgenic Crops: 2007".[84]

Farmers have widely adopted GM technology (see figure). Between 1996 and 2011, the total surface area of land cultivated with GM crops had increased by a factor of 94, from 17,000 square kilometers (4,200,000 acres) to 1,600,000 km^2 (395 million acres).[42] 10% of the world's crop lands were planted with GM crops in 2010.[42] 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.[42] 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.[85] Without it, farmers had to plant rows far enough apart to control post-emergent weeds with mechanical tillage.[85] 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 2009/10, 93% of the planted area of soybeans, 93% of cotton, 86% of corn and 95% of the sugar beet were genetically modified varieties.[86][87][88] Genetically modified soybeans carried herbicide-tolerant traits only, but maize and cotton carried both herbicide tolerance and insect protection traits (the latter largely the *Bacillus thuringiensis* Bt insecticidal protein).[89] These constitute "input-traits" which are aimed to financially benefit the producers, but may have indirect environmental benefits and marginal 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.[90]



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.[42]

Europe has relatively few genetically engineered crops[91] with the exception of Spain where one fifth of maize grown is genetically engineered,[92] and smaller amounts in five other countries.[93] The EU had a 'de facto' ban on the approval of new GM crops, from 1999 until 2004;[94] in a controversial move.[95] GM crops are now *regulated* by the EU.[96] Developing countries grew 50 percent of genetically engineered crops in 2011.[42]

In recent years there has been rapid growth in the area sown in developing countries. A total of 29 countries worldwide grew GM crops in 2011 by approximately 16.7 million farmers and 50% of GM crops grown worldwide were grown in developing countries. For example, the largest increase in crop area planted to GM crops in 2011 was in Brazil (303,000 km^2 versus 254,000 km^2 in 2010). There has also been rapid and continuing expansion of GM cotton varieties in India since 2002 with 106,000 km^2 of GM cotton harvested in India in 2011.[42] However the use of GM crops in India has been controversial, as discussed in detail in the GM controversies article.

According to the 2011 ISAAA brief: "While 29 countries planted commercialized biotech crops in 2010, an additional 31 countries, totaling 60 have granted regulatory approvals for biotech crops for import for food and feed use and for release into the environment since 1996.... A total of 1,045 approvals have been granted for 196 events (NB: an "event" is a specific genetic modification in a specific species) for 25 crops. Thus, biotech crops are accepted for import for food and feed use and for release into the environment in 60 countries, including major food importing countries like Japan, which do not plant biotech crops. Of the 60 countries that have granted approvals for biotech crops, USA tops the list followed by Japan, Canada, Mexico, South Korea, Australia, the Philippines, New Zealand, the European Union, and Taiwan. Maize has the most events approved (65) followed by cotton (39), canola (15), potato and soybean (14 each). The event that has received regulatory approval in most countries is herbicide tolerant soybean event GTS-40-3-2 with 25 approvals (EU=27 counted as 1 approval only), followed by insect resistant maize MON810 with 23 approvals, herbicide tolerant maize NK603 with 22 approvals each, and insect resistant cotton (MON1445) with 14 approvals worldwide."[42]

Examples of genetically modified crops

Currently, there are a number of food species for which a genetically modified version is being commercially grown (percent modified in the table below are mostly 2009/2010 data).[87][88][97][98][99][100]

Crop	Properties of the genetically modified variety	Modification	Percent modified in US	Percent modified in world
Alfalfa	Resistance to glyphosate or glufosinate herbicides	New genes added/transferred into plant genome.	Planted in the US from 2005–2007; 2007–2010 court injunction; 2011 deregulated	
Canola/ Rapeseed	Resistance to herbicides (glyphosate or glufosinate), high laurate canola,[101] Oleic acid canola[102]	New genes added/transferred into plant genome	87% (2005 data[100])	21%
Corn, field (Maize)	Resistance to glyphosate or glufosinate herbicides. Insect resistance via producing Bt proteins, some previously used as pesticides in organic crop production. Added enzyme, alpha amylase, that converts starch into sugar to facilitate ethanol production.[103]	New genes, some from the bacterium Bacillus thuringiensis, added/transferred into plant genome.[104]	86%[87]	26%
Cotton (cottonseed oil)	Kills susceptible insect pests	gene for one or more Bt crystal proteins transferred into plant genome	93%	49%
Papaya (Hawaiian)	Resistance to the papaya ringspot virus.[105]	New gene added/transferred into plant genome	80%	
Potato (food)	NewLeaf: Bt resistance against Colorado beetle and resistance against Potato virus Y (removed from market in 2001[77])	New Leaf: Bt cry3A, coat protein from PVY[106]	0%	0%
Potato (starch)	Amflora: resistance gene against an antibiotic, used for selection, in combination with modifications for better starch production[107]	Amflora – antibiotic resistance gene from bacteria; modifications to endogenous starch-producing enzymes	0%	0%
Rice	Golden Rice: genetically modified to contain beta-carotene (a source of vitamin A)	Current version of Golden Rice under development contains genes from maize and a common soil microorganism.[108] Previous prototype version contained three new genes: two from daffodils and the third from a bacterium	Forecast to be on the market in 2014 or 2015[109]	
Soybeans	Resistance to glyphosate (see Roundup Ready soybean) or glufosinate herbicides; make less saturated fats;[110] Kills susceptible insect pests	Herbicide resistant gene taken from bacteria inserted into soybean; knocked out native genes that catalyze saturation; gene for one or more Bt crystal proteins transferred into plant genome	93%	77%
Squash (Zucchini/Courgette)	Resistance to watermelon, cucumber and	Contains coat protein genes of viruses.	13% (figure is from 2005)[100]	

	zucchini/courgette yellow mosaic viruses[102][111][112]			
Sugar beet	Resistance to glyphosate, glufosinate herbicides	New genes added/transferred into plant genome	95% (2010); regulated 2011; deregulated 2012	9%
Sugarcane	Resistance to certain pesticides, high sucrose content.	New genes added/transferred into plant genome		
Sweet peppers	Resistance to cucumber mosaic virus[113][114]	Contains coat protein genes of the virus.		Small quantities grown in China
Tomatoes	Suppression of the enzyme polygalacturonase (PG), retarding fruit softening after harvesting,[115]while at the same time retaining both the natural color and flavor of the fruit	A reverse copy (an antisense gene) of the gene responsible for the production of PG enzyme added into plant genome	Taken off the market due to commercial failure.	Small quantities grown in China
Wheat	Resistance to glyphosate herbicide	New genes added/transferred into plant genome	unknown	unknown

Effects on farming practices

Managing emergence of resistance

Constant exposure to a toxin creates evolutionary pressure for pests resistant to that toxin.

One method of reducing resistance is the creation of non-Bt crop refuges to allow some nonresistant insects to survive and maintain a susceptible population. To reduce the chance an insect would become resistant to a Bt crop, the commercialization of transgenic cotton and maize in 1996 was accompanied with a management strategy to prevent insects from becoming resistant to Bt crops, and insect resistance management plans are mandatory for Bt crops planted in the USA and other countries. The aim is to encourage a large population of pests so that any resistance genes that are recessive are greatly diluted within the population.[116]

This means that 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 they reach maturity, thus preventing transmission of the resistance gene to their progeny.[117] The planting of refuges (i. e., fields of nontransgenic plants) adjacent to fields of transgenic plants 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 would remain low.

Nevertheless, limitations can affect the success of the high-dose/refuge strategy. For example, expression of the Bt gene can vary. For instance, if the temperature is not ideal, this stress can lower the toxin production and make the plant more susceptible. More importantly, reduced late-season expression of toxin has been documented, possibly resulting from DNA methylation of the promoter.[118] So, while the high-dose/refuge strategy has been successful at prolonging the durability of Bt crops, this success has also had much to do with key factors independent of management strategy, including low initial resistance allele frequencies, fitness costs associated with resistance, and the abundance of non-Bt host plants that have supplemented the refuges planted as part of the resistance management strategy.[119]

Companies that produce Bt seed are addressing this as well, by introducing plants with multiple Bt proteins. Monsanto did this with Bt cotton in India, where the product was rapidly adopted.[120]

Regulation

Main article: Regulation of the release of genetic modified organisms

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 the products of the genetic engineering. For example, a crop not intended for food use is generally not reviewed by authorities responsible for food safety

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Controversy

Main article: Genetically modified food controversies

Critics have objected to GM crops per se on several grounds, including ecological concerns, and economic concerns raised by the fact these organisms are subject to intellectual property law (although this latter issue applies equally to any plant variety). GM crops also are involved in controversies over GM food with respect to whether food produced from GM crops is safe and whether GM crops are needed to address the world's food needs. See the genetically modified food controversies article for discussion of issues about GM crops and GM food. These controversies have led to litigation, international trade disputes, and protests, and to restrictive legislation in most countries.[123]

See also

- Genetic engineering
- Genetically modified food
- Genetically modified food controversies
- Genetically modified organisms
- Regulation of the release of genetic modified organisms

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