Genetic Modification of Crop Plants: Issues and Challenges

Faheema Khan and Khalid Rehman Hakeem

Abstract The growing area of genetically modified (GM) crops has significantly expanded since they were first commercialized in 1996. Currently 400 million acres of the fertile land worldwide are used to cultivate genetic engineering (GE) crops such as rice, corn, cotton, and soybeans. Genetically modified crops are increasingly gaining acceptance and their adoption has brought huge economic and environmental benefits. In the past 17 years, these achievements have been primarily supported by two simple traits of herbicide tolerant and insect resistant crops. Concurrently GM crops generated intense consumer debate in many parts of the world. The issues under debate include the costs and benefits of the GM crops and the inherent safety concerns. It is widely claimed, however, that biotechnology, particularly genetically engineered food offers dramatic promise for meeting some of the twenty-first century's greatest challenges; as do all new technologies, it also poses certain apprehensions and risks, both known and unknown. The introduction of *Bacillus thuringiensis* (Bt) genes into the plants has raised issues related to its risk assessment and biosafety. The chapter presents an overview of the production of GM crops, their adequacy, detection strategies, biosafety issues, and potential impact on society. Furthermore, the future prospects of the GM crops are also highlighted.

Keywords GM crops • *Bacillus thuringiensis* • Biotechnology • Crop resistance

F. Khan (✉)
Department of Botany and Microbiology, College of Science King Saud University, Riyadh 11495, Kingdom of Saudi Arabia
e-mail: deffodils@gmail.com

K.R. Hakeem
Faculty of Forestry, Universiti Putra Malaysia, 43400-Serdang, Selangor, Malaysia

K.R. Hakeem (ed.), *Crop Production and Global Environmental Issues*,
DOI 10.1007/978-3-319-23162-4_16

1 Introduction

In the present scenario of a growing population, global warming and diminishing biodiversity have a remarkable influence on our environment. The world population has increased by 2.3 billion people in the past 40 years (Hakeem et al. 2012). It is likely by the year 2050, there will be 9.3 billion people living on Earth and 50 years in the future the world population is expected to surge by three billion. The biggest challenge is to feed this enormous number which leads to extensive modifications in the production, dispersal, and constancy of crop yield. Inopportunely, the cultivable land and population are not equivalently dispersed. The main factors are decreasing cropland due to soil erosion, water scarcity, fewer renewable resources, and insufficient manpower. Moreover, the devastation of wilderness, afforestation, and constant usage of fuel resources have immensely increased carbon dioxide levels, resulting in global warming. Based on numerous studies covering an extensive range of regions and crops, it has been reported that negative impacts of climate change on crop production have been more common than positive impacts; moreover, global climate change at rates slower than the current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Change in climate can drastically modify rainfall patterns and consequently require the relocation of people and changes in agricultural and production practices. Conventionally agriculture production has been supported by technological advancement, mostly in the field of genetic crop improvement. For several years, the agriculture industry has been searching and exploiting the genetic traits of seeds in search of healthy and productive varieties. There are several ways that can enhance agricultural productivity in a sustainable way, including the use of fertilizers, improved pest control, soil conservation, and by selecting better plant seeds, produced by both traditional and biotechnological means. Among these methods, biotechnological applications, particularly production of transgenic plant varieties and future functional genomic projects, possibly hold the potential to extend agricultural productivity when suitably incorporated into conventional methods. Genetically modified seeds are a major step in advancing the agricultural production.

Genetically modified organisms (GMOs) are the ones in which the genomic material, DNA (deoxyribonucleic acid), has been transferred from a bacterium or a plant, or even an animal, into a different plant species to obtain the desired and improved quality. Genetic engineering modifies the genetic material of crops to display specific traits (Fernandez-Cornejo and Caswell 2006). This technology is often recognized as “recombinant DNA technology” or “genetic engineering” and the resultant organism is said to be “genetically engineered,” “genetically modified,” or “transgenic.” Presently GM products include foods and food ingredients, feeds and fiber, medicines, and vaccines. Although it is extensively claimed that biotechnology, mainly genetically engineered crops offers strong promise for meeting some of the twenty-first century’s utmost challenges, it also poses certain risks and apprehensions both known and unknown. It is, therefore, paramount in this perspective, to know the basic procedures involved in genetic modification for suitable appreciation of the related issues and challenges.

1.1 Genetic Engineering: The Technique

All living entities from plants, animals, and human beings are made up of cells. The nucleus comprises a unique set of information concerning their size, shapes, and qualities. These instructions are found on a DNA fragment, which is divided into sections called genes. The sequence of genes on DNA determines the characteristics of an organism. The complete set of genetic material of an organism is known as the genome. The method of isolating genes from the genome of one organism and inserting them into the genome of another organism in order to modify it for the desired trait is known as genetic engineering (Vert et al. 2012). Plants, animals, or microorganisms that have transformed through genetic engineering are termed genetically modified organisms. The modified organism carries the new genes to its progeny. The methodology is now in practice to produce GM plants of desired growth and quality. The main purpose is to produce the varieties with high yield, disease/pest resistance, and other such assets for better durability and market value. This process is different from modifying crop plants through customary mutation breeding or selective breeding by farming activities (Kavitha et al. 2007). By the year 2012, the most successful GM plant has gene transformation that provides defense against herbicides and insects (James 2012). Gene isolation is carried out by using restriction enzymes to cut the DNA into small fragments followed by gel electrophoresis to separate them out according to their length and size (Alberts et al. 2002). A polymerase chain reaction (PCR) is used to amplify gene segments, which can then be isolated through gel electrophoresis (Kaufman and Nixon 1996). If the selected gene or the donor organism's genome has been studied, it may possibly be available in a genetic library, but if the DNA sequence is unknown, it can be synthesized artificially (Liang et al. 2013). In order to work properly the selected gene to be inserted into the genetically modified organism must be combined with other genetic elements. The gene can also be altered at this stage for effectiveness and better expression; for this the constructs contain a promoter and terminator region as well as a selectable marker gene. The promoter region initiates transcription of the gene and can be used to regulate the site and level of gene expression, whereas the terminator region finishes transcription. The constructs are prepared using recombinant DNA techniques, such as restriction digestion, ligations, and molecular cloning (Berg and Mertz 2010).

1.2 Genetically Modified Crops

The first genetically modified crop was produced in 1982, utilizing the antibiotic-resistant tobacco plant (Fraley 1983). In 1986 the first trial of genetically modified plants occurred in the fields of the United States and France, where tobacco plants were engineered for resistance against herbicides (James 1996). In 1987, Plant Genetic Systems (Ghent, Belgium), established by Marc Van Montagu and Jeff Schell, was the pioneer company to grow genetically modified tobacco plants with insect resistance by expressing genes encoding for insecticidal proteins from *Bacillus thuringiensis* (Bt; Vaeck 1987). In 1992, China was the first country to allow commercialized transgenic plants (virus-resistant tobacco; James 1997) which was later withdrawn from the market in 1997 (Conner et al. 2003). The first genetically modified crop permitted for sale in the United States, in 1994, was the tomato called FlavrSavr which is modified to ripen without softening by a California company, Calgene (Bruening and Lyons 2000). In 1994, the European Union allowed the tobacco plant engineered to be herbicide resistant, bromoxynil, making it the first commercial genetically modified crop in the European market (MacKenzie 1994). In 1995, Bt Potato was approved safe by the Environmental Protection Agency, making it the first pesticide-producing crop to be permitted in the United States (USDA 2000).

In 2012, more than 420 million acres of GE crops were cultivated in 28 countries contributing approximately 10 % of global cropland (ISAA 2012). Several food crops have been modified to increase production and durability; the examples are cotton, sugarcane, tomatoes, soybean, Hawaiian papaya, potatoes, rice, rapeseed, sugar beet, field corn, and sweet corn. Plant geneticists are also investigating other crops they expect will be beneficial for the commercial industry, such as oil-producing plants for cosmetics, crops with traits to provide nutritional fortification, and even crops that produce pharmaceutical drugs (Fernandez-Cornejo 2006). The major transgenic crop-producing countries are the United States, Canada, India, South Africa, China, Argentina, and Brazil. Most genetically engineered crops are transformed to be either herbicide tolerant, to destroy weeds without damaging crops, or insect resistant, to shield plants from harmful pests. After nearly 20 years, only one high-yield GE seed has been considered for approval (USDA 2013).

2 Benefits of Genetically Modified Food

2.1 Increased Crop Yields

It is widely expected by those in crop production that genetically engineered seeds will increase the yields of farmers who implement the technology in the fields. Although there is not much research available regarding the impact of genetic engineering in increasing crop production, available research supports these expectations. In 1997, the Economic Research Service (ERS) found a statistically significant association between improved crop yields and increased adoption of pesticide and herbicide resistant crop seeds (ERS 2000). The ERS study also reported that crop yields significantly increased when farmers adopted herbicide-tolerant cotton and Bt cotton. Another study performed by Iowa State University (USA) reported Bt crops had higher yield over non-Bt crops. The university studied 377 cultivated fields and calculated that crops grown from GM seeds yielded 160.4 bushels of Bt corn per field, whereas crops grown from non-GM seeds yielded 147.7 per field.

2.2 Herbicide Tolerant and Pest Resistant Crops

Eradicating weeds in physical ways such as tilling is not cost effective. To destroy weeds, farmers often spray large quantities of different herbicides, which are an expensive and laborious process involving caution so the herbicide doesn't harm the crops and environment. Herbicide-tolerant crops are aimed to resist specific herbicides. Herbicides are designed to work with particular herbicide-tolerant seeds that can kill weeds without causing any detrimental effect on genetically engineered crops. Most of these crops are resistant to the herbicide glyphosate commercially sold as Roundup (manufactured by the agrichemical company Monsanto) (Fernandez-Cornejo 2004a, b). In 2012, Monsanto's Roundup was present in 86 % of the US GE cotton market and 98 % of the US GE corn market. Monsanto has created a genetically modified soybean strain that is unaffected by their herbicide product Roundup. Farmers cultivate these soybeans, which then only require one application of herbicides instead of several applications, dropping production cost and minimizing the hazards of agricultural waste (USDA 2013). Other known herbicide resistant crops include Calgene's BXN cotton and Bayer's Liberty Link corn (USDA, ERS 2013a, b). Crop losses from insects and pests can be surprising, causing an immense economic loss for farmers and food shortages in developing countries. To overcome this loss farmers annually apply several tons of chemical pesticides. Due to the potential health hazards of pesticides, consumers hesitate to eat food that has been treated with chemicals, also agronomic wastes from extreme use of pesticides and fertilizers can contaminate the water supply and cause detrimental effects to the environment. Growing genetically modified crops such as Bt corn can reduce the application of chemical pesticides and reduce the cost of crop production (US Patent 6313378 2001). The *Bacillus thuringiensis* soil bacterium gene is designed to resist the European corn borer and numerous cotton bollworms (Fernandez-Cornejo 2004a, b). An entomologist from the University of Missouri found that corn rootworms could pass on Bt resistance to their offspring. University of Arizona scientists found that within seven years of Bt cotton introduction, cotton bollworms developed Bt resistance which they later passed on to offspring, signifying that the resistance was dominant and could evolve quickly.

2.3 Disease Resistance

There are many microorganisms and entities such as bacteria, fungi, and viruses that cause plant diseases. Researchers are working on several projects to construct genetically modified plants that show resistance to these diseases (Dahleen 2001). Fungi cause a range of severe plant diseases such as grey mould, blight, powdery mildew, and downy mildew. Fungal plant diseases are generally coped with by the use of chemical fungicides. Moreover, combating yield losses and avoiding fungal infection saves crops from various mycotoxins produced by pathogenic fungi. Mycotoxins can affect the immune system and interrupt the hormone balance; a few of them are also carcinogenic. Genetic engineering facilitates novel means of managing fungal infections by transferring genes from other bacteria or plants encoding enzymes such as glucanase or chitinase. These enzymes further break down glucan and chitin, which are vital constituents of fungal cell walls. Some other approaches include provoking a hypersensitive response. The spread of most viruses is very difficult to control. Once the infection is established, no chemical treatment or methods are available to stop the same. Genetic engineering can also be used to develop virus resistant plants. The most common method to exploit this technique is by inserting a plant with a viral gene encoding the virus coat protein. The plant can then produce this viral protein before the virus infects the plant. Papaya ring spot potyvirus is a severe viral disease of papaya, which inhibits photosynthesis in plants and stunts growth. Genetic engineering proved to be successful in producing virus resistant GM papayas.

2.4 Drought and Salinity Tolerance

Creating drought or salinity tolerant crops was a great task, but improvements were made through a stepwise methodology. Recent inventions in biotechnology are conveying a better understanding of the pathways and mechanisms involved in drought and salinity tolerance. Developing crops that can resist extensive durations of drought or salinity in soil and groundwater will encourage people to cultivate crops in earlier inhospitable areas (Tang 2000; Zhang and Blumwald 2001). Several drought and salt tolerant genes have been recognized. Identification of these salt regulated genes has allowed a better understanding of the complexity of higher plants (Hasegawa et al. 2000). Research institutes such as ICARDA developed drought and salt tolerant wheat and barley exploiting genetic engineering.

2.5 Pharmaceutical Crops

GE crops comprise genes that are beneficial for pharmaceutical industries. Medicines are often expensive to produce and generally need special storage conditions not freely accessible in developing countries. Scientists are working to produce edible vaccines in potatoes and tomatoes (Daniell et al. 2001; Qingxian et al. 2001). These vaccines will be considerably easier to transport, store, and manage than conventional injectable vaccines. The USDA has permitted field trials for a safflower variety that is genetically modified to produce a precursor to human insulin that can be used for diabetes treatment (SemBioSys 2010).

2.6 Nutrition-Added Crops

Various GE crops can modify the nutritional value of a food and are therefore encouraged by biotech industries as a promising solution against diseases. Malnutrition is one of the biggest threats in third-world countries. Underprivileged people mainly depend on rice as a staple food. Rice, however, does not have sufficient quantities of all required nutrients to prevent malnutrition. Giving significance to malnutrition, rice has been genetically modified to contain surplus vitamins and additional minerals in order to alleviate the nutritional value. "Golden Rice" is a variety boosted with an organic compound, carotene. The rice has been modified to decrease the occurrence of vitamin A deficiency in the developing world (Xudong 2003). Similarly, GE soybean and canola oil are engineered to ensure lesser polyunsaturated fatty acid content and higher monounsaturated fatty acid levels (oleic acid) (WHO 2008). In 2010 the USDA permitted a novel soybean brand that is modified to produce more oleic acid (75Fed. Reg. 32356).

3 Important GE Crops

3.1 Safflower

The USDA in 2007 permitted a field trial of a safflower variety engineered by the Canadian company SemBioSys. It was tested to produce proinsulin, a precursor to insulin in humans (73Fed. Reg. 8847-8848; 2008). Although safflower self-pollinates, some insects can still cross-pollinate safflower plants with genetically engineered pharmacological qualities (USDA 2007). Regardless of the contamination threat, SemBioSys has a pending application to bring the GE pharmaceutical to market (USDA 2011a, b, c, d).

3.2 Soybean

Soybean is among the two most extensively grown GE crops. The USDA has released two soybean varieties engineered to have healthier oil profiles (Shoemaker 2001). Furthermore in December 2011, the USDA approved a novel soybean genotype that was lower in saturated fat, and in July 2012 it approved a soybean with higher level omega-3 fatty acids (USDA 2011a, b, c, d).

3.3 Sugar Beet

In 2005, after determining that genetically modified production posed no threats to other plants and the environment, the USDA approved Monsanto's Roundup Ready sugar beet (70 Fed Reg 13007-13008; 2005). In 2008, the Center for the Food

Security Club confronted this approval in law court on the basis that the USDA's environmental assessment overlooked significant economic and environmental impacts (69 N.D. Cal 2010). In July 2012, the USDA finally approved GE sugar beets.

3.4 Sweet Corn

Monsanto in 2011 announced that Roundup Ready sweet corn would be engineered for implanting (Gilliam 2011). Sweet corn is Monsanto's first commercialized GE vegetable crop approved by the USDA.

3.5 Tomato

In 1991, DNA Plant Technology Corporation transferred a gene from the flat fish winter flounder to produce a cold-tolerant tomato (USDA 2011a, b, c, d). It was later approved for field testing, but was never approved for commercialization (USDA 2011a, b, c, d). In 1992, Calgene engineered the tomato called Flavr Savr having a longer shelf life and was the first GE crop on the market. Later it was withdrawn from the market due to harvesting difficulties and lower demand (USDA, ERS 2013a, b).

3.6 Wheat

In 2002, Monsanto appealed the USDA for the approval of Roundup Ready red spring wheat. It was the first GE crop modification for human food consumption other than livestock feed. In 2004, an Iowa State study predicted that allowing genetically modified wheat could decrease US wheat exports by 30–50 % and reduce costs for both GE and conventional wheat (USDA 2013). Monsanto abandoned GE wheat field tests before getting commercial agreement, although the company continued research in 2009.

3.7 Alfalfa

Alfalfa is an important feed crop for livestock. The USDA permitted Monsanto's Roundup Ready alfalfa in 2005. In 2007, non-GE alfalfa producers challenged the USDA's permit on the basis that GE alfalfa might contaminate organic alfalfa (CRBNo. C06-01075; 2007). In 2010 a USDA environmental impact statement confirmed the possible harmful impacts of organic and conventional alfalfa growers, including lower demand in the market due to adulteration (USDA 2010). Nevertheless, in 2011 the USDA approved genetically engineered alfalfa deprived of any planting restrictions (76. Fed. Reg. 8708; 2011).

3.8 Corn

The USDA in 2011 allowed Syngenta's amylase corn with distinctiveness to produce an enzyme that accelerates the production of ethanol. The USD assured that it was harmless for food and livestock feed and allowed it for field trials (USDA 2011a, b, c, d).

3.9 Papaya

In 1999, the EPA approved two varieties of papaya that are resistant to the papaya ring spot virus (Fernandez 2006). Genetically engineered papayas contributed 30 % of Hawaii's papaya production in 1999 increasing to 77 % by 2009. Moreover, the third ring spot-resistant papaya was approved by the USDA in 2009 (74. Fed. Reg. 45163; 2009).

3.10 Potato

The EPA and FDA in 1995 permitted Monsanto's Colorado potato beetle resistant New leaf potato (Monsanto 2010). Later in 2001, Monsanto withdrew the potato commercialization, but in 2010, the European Union approved the Amflora potato for farming which is a product of the German chemical company BASF, although the crop is intended for industrial use only such as paper and textiles (BASF 2010). The USDA is seeking for the approval of a low-acrylamide and reduced-bruising potato created by McDonald's main supplier J. R. Simplot (BSPR 2013).

3.11 Rice

The Rockefeller Foundation in 1982 launched a modified variety called Golden Rice to combat a deficiency of vitamin A. In the first field test of golden rice the strain was found unsuccessful in providing enough beta carotene to meet the Vitamin A deficiency (Brown 2001). In 2004 Syngenta tested 2-Golden Rice in fields at Louisiana State University.

4 Concern Against GM Foods

Scientists, environmentalists, professional associations, public interest groups, and other government representatives have all raised concerns about genetically modified food and criticized the agro industry for earning profits without concern for potential health hazards. Critics also pointed to government for failing to implement adequate regulatory measures. Utmost concerns about GM foods are human health risks, environmental safety, and economic issues.

4.1 Environmental Safety

4.1.1 Effect of GE Pesticides

The US Environmental Protection Agency set a regulation of pesticides and herbicides, together with GE crops that are modified to be insect resistant. The EPA also sets tolerable levels of pesticide and herbicide remains in food, including GE insect tolerant crops. During the year 1995–2008 the EPA listed 29 GE pesticides modified into cotton, corn, and potatoes. In 1947, bioengineered insecticides were regulated under the Federal Insecticides, Fungicide, and Rodenticide Act (FIFRA 1998). Pesticide and insecticide resistance GE crops need to prove they do not cause any adverse effects on the environment or public health. The biotech industries must conduct field trials for insect tolerant GE crops, create tolerable pesticide characteristics, and record the pesticide trait for commercial production (CFR 2001). A study showed that pollen from Bt corn caused high mortality rates in monarch butterfly caterpillars (John et al. 1999). Unfortunately Bt toxins destroy several species of insect larvae indiscriminately. It is impossible to design a Bt toxin that would only target crop damaging pests and remain harmless to all other insects. This study has been later investigated by the EPA and other nongovernmental research agencies; the initial data from new findings propose that the original study may have been flawed (Niiler 1999). This topic is highly debatable and both sides are defending their data strongly. Presently, there is no conclusion about the Bt studies and the potential risk of harm to nontarget organisms requires further evaluation.

4.1.2 Reduced Efficacy of Pesticides

Farmers are concerned that usage of GM seeds may reduce efficiency of pesticides. Several populations of mosquitoes developed resistance to the currently banned pesticide DDT.A study reported a decreased susceptibility in pests to the use of Bt as a sprayed pesticide (www.colostate.edu).

4.2 Development of Resistant Weeds and Insects

When the crop is grown nearby a closely related weed species, gene transfer from GE crop to weed through pollen transfer has been verified (www.colostate.edu). The crossbreeding transfer of the herbicide resistant genes will create superweeds or superbugs that may possibly develop a resistance to GM crops and insecticides.

5 Effect on Consumers

5.1 Ambiguous Safety

The effects of GM crops on human health are not yet identified. GE food like non-GE food can carry hazards to consumers such as potent allergens and toxins. Evidence proves that human reaction to allergens will be similar when it is transferred to GE organisms. A study found that persons allergic to nuts responded in a similar way to genetically engineered soybeans in which a protein from a Brazil nut was introduced. However, very little evidence supports a significant health hazard of GM crops to consumers. The Centers for Disease Control also found no evidence between a processed food that contained a GM product and claimed to be allergic (Bonalume 1999). Moreover the GM industry identified that the local market consumers of GM products for years have no associated health hazards (Hodgson 1999). Corn and soybeans are the major GE food crop of the industrial food supply, from vegetable oils to high-fructose corn syrup to livestock feed. Safety studies on GE food are insufficient as biotech companies prohibit production for research purposes in their seed licensing contract. A toxicologist reported in a study that rats fed on GE corn over two years had deteriorated liver and kidney functioning and also had high chances for tumor development (Gilles-erec 2011). Another study reported impaired embryonic development and abnormalities in the livers of mice as well as in rats fed GE soybean (Malatesta et al. 2002). In 2007 a study found liver damage and kidney impairment of rats that were fed insect tolerant Bt corn (Gilles-erec 2007).

Studies indicate that the Roundup Ready attribute lowers the nutritional content of engineered crops by constraining the absorption of nutrients such as iron, calcium, zinc, and magnesium making plants more disease vulnerable (Huber 2010). A study reported that fusarium, a pathogenic fungi that infects plant roots, becomes more dominant over Roundup-treated crops (Johal and Huber 2009).

5.2 Identity Preservation in Field and Markets

Labeling of GM foods and food products is also an important issue. For consumers to have the opportunity to make selections about their food, all GE foods should be labeled. The agro-industry considers that food labeling should be voluntary and subject to the requirements of the free market. Consumer interest groups are also demanding obligatory labeling on GM food. The FDA's recent status for food labeling is administered by the Food, Drug and Cosmetic Act. The FDA is only concerned with food additives, not whole foods that are considered "GRAS," generally recognized as safe. There are some other queries that need to be responded to if the labeling of GM foods becomes obligatory. Firstly, the agronomist will absorb the cost of such an initiative in order to save GM crops and non-GM crops from mixing during harvesting and shipping. It is almost assured that manufacturers will pass along these added expenses to consumers in the form of higher prices. Secondly, the suitable limits of GM adulteration in non-GM products, where the acceptable limit of cross-contamination is 1 % is determined by the EC, yet several consumer groups debated that only 0 % is adequate. Researchers concluded that present technology is incompetent to identify minute amounts of contamination, so safeguarding 0 % contamination is not guaranteed. Finally, the utmost challenge confronted by a new food labeling policy is to educate and notify consumers without damaging the public trust and causing alarm or fear of GM food products.

6 Economic Concerns of GM Products

Bringing a GM food from field to the local market is an extensive and expensive process and agro companies wish to ensure a commercial profit on their investment. Unions combined with patent restrictions have increased the economic power of biotechnology companies. Consumers are concerned that patenting improved plant varieties will increase the price of seeds which will be unaffordable for farmers and third-world countries. Biotech corn seed prices rose by an average of 13 % annually between 2002 and 2012, and soybean seed prices increased by an average of 11 % annually. Between 1996 and 2007, Monsanto acquired more than a dozen seed companies. Strict patents preserve genetically engineered varieties and violation of such patents is of great concern for an agro-industry. The patent holder controls how partnering companies utilize the combined traits. Therefore, there are several seed companies; most of the accessible soybean, cotton, and corn seeds contain Monsanto-patented traits that have been cross-licensed to other seed-producing companies (David 2004) Agriculturalists pay patent tolls and sign a bond for limited authorization to plant GE seeds. Growers need to purchase new seeds every year due to patent infringement. However, this would be financially disastrous for farmers in third-world countries who cannot afford to buy seed each year and traditionally set aside a portion of their harvest to plant in the next growing season.

7 Global Trade

GM crops and GM products are not universally accepted in the global market. The United States has eagerly permitted GE crops, whereas consumers in Japan and Italy are doubtful about the safety of GE foods. The European Union has banned the import of crops with inserted genes, referring to concerns about the environment and human health hazard. Presently some EU countries prohibit GE cultivation altogether: France, Germany, Austria, Luxembourg, Greece, and Hungary. Nations that prohibit GE food normally enforce strict rules to avoid illegal GE imports which blocks US exports of soybean and corn that are major GE food crops. Japan does not produce GE crops and needs obligatory labeling of all GE food. In spite of the modern grain-handling arrangement in the United States, GE grains have contaminated non-GE shipments. The Government Accountability Office recognized six known unlicensed releases of GE crops between 2000 and 2008. In 2000, Japan noticed GE StarLink corn which was not allowed as fit for the human diet.

After the Star Link exposure, Europe banned all US corn shipments, costing crop producers $300 million. In August 2006, non-licensed GE Liberty Link rice was found to have contaminated conventional rice stocks. Europe and Japan enforced heavy restrictions and ceased all US rice imports costing the US rice producers $1.2 billion. In recent years, the US Trade Representative has been pushing transaction partners to eliminate unnecessary import prohibitions and limitations to US GE crops and GE products and is even insisting countries remove GE labeling necessities (USTR 2010). Moreover the US State Department has pressured governments all over the world to lift GE restrictions (U.S. (DoS) 2007).

8 Future Prospects and Conclusion

There are many potential reasons to believe that current and future GM crops have the greatest potential to benefit economic, ecological, and evolutionary components of sustainable crop production in the future. Increasingly, the use of GM crops will require agronomists, ecologists, farmers, and policy makers alike to take more of a systems perspective that considers the broader evolutionary consequence of the traits in question. However, engineering crops with complex traits such as abiotic stress tolerance, nutrition use efficiency, and yield potential remains difficult, although they are highly desirable in agricultural production. A great number of genes have proven effective under well-controlled conditions, but are generally not good enough when tested in the field. More and more research is needed through the integration of GM crops as the basic strategy for successful management of pests, diseases, and weeds in an agro-ecosystem. The safety assessment of foods derived from GM crops conferring nutritional benefits may in some cases require the development of improved in vivo dietary studies of whole foods. It is important to develop animal models that are very sensitive to the detection of toxic and antinutritive effects and intended positive nutritive effects. Toxicological tests should be considered on a case-by-case basis, for example, proliferative changes in tissues during the 90-day study may indicate the need for a long-term toxicity study. In addition to animal studies designed specifically for safety evaluation, nutritional or wholesomeness testing may be performed to determine whether the food or feed product of the GM crop poses any nutritional problems in comparison with the unmodified parent crop (Hammond 1996). There are many challenges ahead for biotech companies and government mainly in the areas of human health hazard, food labeling, safety trials, and international policies. There are opinions of the scientists that genetic engineering is an inevitable movement and we cannot afford to overlook a technology that has such enormous potential benefits. However, we need to progress with caution to escape unintentional impairment to human health and the environment as a consequence of our interest in this influential technology.

References

40 CFR 172.3(a), 40 CFR 180, 40 CFR 152.1(a) (2001) Pew initiative on food and biotechnology, pp 13–14

Alberts B, Johnson A, Lewis J (2002) Isolating, cloning, and sequencing DNA, 4th edn. Garland Science, New York

BASF (2010) European Commission approves Amflora starch potato (Press Release). Available at http://www.basf.com/group/pressrelease/P-10-179

Berg P, Mertz JE (2010) Personal reflections on the origins and emergence of recombinant DNA technology. Genetics 184:9–17

Bonalume-Neto R (1999) Smugglers aim to circumvent GM court ban in Brazil. Nature 402:344–345

Brown P (2001) GM rice promoters have gone too far. Guardian

Bruening G, Lyons JM (2000) The case of the FLAVR SAVR tomato. Calif Agric 54:6–7

Center for Food Safety v. Thomas J Vilsack (N.D.Cal 2010) No. C10-04038 JSW 15

Colorado State University, Transgenic crops: an introduction and resource guide. http://www.colostate.edu/programs/lifesciences/TransgenicCrops/risks.html

Conner AJ, Glare TR, Nap JP (2003) The release of genetically modified crops into the environment. Part II. Overview of ecological risk assessment. Plant J 33:19–46

Dahleen LS (2001) Transgenic approaches to combat Fusarium head blight in wheat and barley. Crop Sci 41:628–637

Daniell H, Streatfield SJ, Wyckoff K (2001) Medical molecular farming: production of antibodies, biopharmaceuticals and edible vaccines in plants. Trends Plant Sci 6:219–226

David E (2004) The impact of seed industry concentration on innovation: a study of U.S. biotech market leaders. Agric Econ 30:159–164

Economic Research Service (2000) Genetically engineered crops for pest management, United States Department of Agriculture

Fed. Reg. 13007-13008 (2005)

Fed. Reg. 32356 (2010)

Fed. Reg. 45163 (2009)

Fed. Reg. 8708 (2011)

Fed. Reg. 8847-8848 (2008)

Fernandez-Cornejo J (2004) The seed industry in U.S. agriculture: an exploration of data and information on crop seed markets, regulation, industry structure, and research and development. Information Bulletin No. 786. Resource Economics Division, Economic Research Service, USDA

Fernandez-Cornejo J (2004) The seed industry in U.S. agriculture: an exploration of data and information on crop seed markets, regulation, industry structure, and research and development. Agriculture Information Bulletin No. 786. U.S. Department of Agriculture, Economic Research Service, Washington, DC. Available at http://www.ers.usda.gov/publications/aib786/aib786.pdf. Accessed 26 May 2009

Fernandez-Cornejo J (2006) Pew initiative on food and biotechnology. Review of Public Opinion Research

Fernandez-Cornejo J, Caswell MF (2006) The first decade of genetically engineered crops in the United States. Economic Information Bulletin No. 11. U.S. Department of Agriculture, Economic Research Service, Washington, DC

Food and water watch analysis of data from USDA National Agriculture Statistics Service (NASS) 2000–2012 Price paid for Corn, Cotton, and Soybeans. Data available at http://www.nass.usda.gov/

Food and water watch analysis of U.S. Department of State (DoS) (2007) Cable No. 07STATE160639, 27 Nov 2007; U.S. DoS. FY2009 biotechnology outreach strategy and department resources. Cable No. 08STATE129940

Fraley RT (1983) Expression of bacterial genes in plant cells. Proc Natl Acad Sci 80:4803–4807

Geertson Seed Farms v. USDA (2007) Memorandum and order. United States District Court for the Northern District of California. No. C06-01075 CRB

Gilles-erec S (2007) New analysis of a rat feeding study with a genetically modified maize reveals signs of hepatorenal toxicity. Arch Environ Contam Toxicol 52:596–601

Gilles-erec S (2011) Long term toxicity of a roundup herbicides and a roundup-tolerant genetically modified maize. Food Chem Toxicol 50:1–11

Gilliam C (2011) Monsanto launching its first biotech sweet corn. Reuters, St. Louis, MO

ISAA (2012) Global status of commercialized biotech/GM crops. ISSA Brief No. 44

Hakeem KR, Ozturk M, Memon AR (2012) Biotechnology as an aid for crop improvement to overcome food shortage. In: Ashraf M, Ozturk M, Ahmad MSA, Aksoy A (eds) Crop production for agricultural improvement. Springer Science + Business Media LLC, New York, pp 239–261. doi:10.1007/978-94-007-4116-4_9

Hammond BG et al (1996) The feeding value of soybeans fed to rats, chickens, catfish and dairy cattle is not altered by genetic incorporation of glyphosate tolerance. J Nutr 126:717–727

Hasegawa PM, Bressan RA, Pardo JM (2000) The dawn of plant salt to tolerance genetics. Trends Plant Sci 5:317–319

Hodgson J (1999) EC says 1% is acceptable GMO contamination. Nat Biotechnol 17:1155–1156

Huber DM (2010) Ag chemical and crop nutrient interactions—current update. Proc Fluid Fertil Forum 27:14–16

James C (1996) Global review of the field testing and commercialization of transgenic plants: 1986 to 1995

James C (1997) Global status of transgenic crops in 1997. ISAAA Briefs No. 5: 31.

James C (2012) International service for the acquisition of agri-biotech applications. Global status of commercialized biotech/GM crops. Executive summary. Brief 44

Johal GS, Huber DM (2009) Glyphosate effects on diseases of plants. Eur J Agron 31:144–153

John E, Linda SR, Carter ME (1999) Transgenic pollen harms monarch larvae. Nature 399:214–222

Kavitha K, Ramanjaneyulu GV (2007) Genetic engineering in Indian agriculture - an introductory handbook. Centre for Sustainable Agriculture, Secunderabad

Kaufman RI, Nixon BT (1996) Use of PCR to isolate genes encoding sigma 54-dependent activators from diverse bacteria. J Bacteriol 178:3967–3970

Lepidopteran-resistant transgenic plants (2001) US Patent 6313378-Monsanto

Liang WH, Li L, Zhang F, Liu YX, Li MM, Shi HH et al (2013) Effects of abiotic stress, light, phytochromes and phytohormones on the expression of OsAQP, a rice aquaporin gene. Plant Growth Regul 69:21–27

MacKenzie D (1994) Transgenic tobacco is European first. New Scientist

Malatesta M, Caporaloni C, Gavaudan S, Rocchi MB, Serafini S, Tiberi C, Gazzanelli G (2002) Ultrastructural morphometrical and immunocytochemical analyses of hepatocyte nuclei from mice fed on genetically modified soybean. Cell Struct Funct 27:173–180

Monsanto (2010) The new leaf potato. Available at http://www.monsanto.com/newsviews/Pages/new-leaf-potato.aspx. Accessed 3 Jan 2011

Niiler E (1999) GM corn poses little threat to monarch. Nat Biotechnol 17:1154

Office of the U.S. Trade Representative (2010) Report on sanitary and phytosanitary measures

Qingxian K, Richter L, Yang YF, Arntzen CJ, Mason HS, Thanavala Y (2001) Oral immunization with hepatitis B surface antigen expressed in transgenic plants. Proc Natl Acad Sci 98:11539–11544
Robinson J (2013) Idaho company seeks to introduce genetically engineered potato. Boise State Public Radio. On file and available at http://www.boisestatepublicradio.org./post/Idaho-company-seeks-introduce-genetically-engineered-potato
SemBioSys (2010) Our solution for diabetes. Available at http://www.sembiosys.com/Products/Diabetes.aspx. Accessed 17 Dec 2010
Shoemaker R (ed) (2001) USDA ERS. Economic issues in agriculture biotechnology. AIB-762
Suguro S (2008) USDA. Foreign Agriculture Service, global agriculture information network. Japan biotechnology annual report
Tang W (2000) Peroxidase activity of desiccation-tolerant loblolly pine somatic embryos. In Vitro Cell Dev Biol Plant 36:488–491
U.S.C. prec. 121; EPA (1998) FIFRA amendments of 1998 (Press release)
USDA (2007) Environmental assessment: in response to permit application (06363-103r), received from SemBiosys, Inc. for a field test to produce human proinsulin (line 4438-5A) in genetically engineered safflower seeds, pp 10–11
USDA (2010) Glyphosate-tolerant Alfalfa events J101 AND j163: request for non-regulated status. Final environmental impact statement
USDA (2011) Monsanto improved fatty acid profile MON 87705 soybean petition 09-201-01p: final environment assessment
USDA (2011) APHIS-biotechnology regulatory services. Public permit data
USDA (2011) Environmental assessment and finding of no significant impact. Permit number 91-079-01. 1991. Available at http://www.isb.vt.edu/documents/ea/9107901r.e.a.pdf
USDA (2011) Syngenta Seeds, Inc. Alpha-amylase maize events 3272, draft environmental assessment. 6 Nov 2008, 35-38 USDA. National environmental policy act decision and finding of no significant impact, Syngenta Seeds, Inc., alpha–amylase maize, Event 3272
USDA (2013) Animal and plant health inspection service (APHIS). Petitions for determination of nonregulated status. On file available at http://www.aphis.usda.gov/biotechnology/petitions_table_pending.shtml
USDA, Economic Research Service (ERS) (2013) Adoption of genetically engineered crops in the U.S. Available at http://www.ers.usda.gov/Data/BiotechCrops/. Updated 9 July 2013. Accessed 21 Sept 2013
USDA, Economic Research Service (ERS) (2013) Adoption of genetically engineered crops in the U.S. Available at http://www.ers.usda.gov/Data/BiotechCrops
Vaeck M (1987) Transgenic plants protected from insect attack. Nature 328:33–37
Vert M, Doi Y, Hellwich KH, Hess M, Hodge P, Kubisa P, Rinaudo M, Schué F (2012) Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). Pure Appl Chem 84:377–410
Waters B, Gwenell L (2004) Status of genetically engineered wheat in North America. Congressional Research Service Report, 4 Nov 2004
World Health Organisation (2008) Safety aspects of genetically modified foods of plant origin. Report of a joint FAO/WHO expert consultation on foods derived from biotechnology 2008 at 8
Xudong Y (2003) Engineering the provitamin A biosynthetic pathway into rice endosperm. Science 14:287–303
Zhang H-X, Blumwald E (2001) Transgenic salt-tolerant tomato plants accumulate salt in foliage but not in fruit. Nat Biotechnol 19:765–768