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Policy Paper

Genetically modified food: benefits, safety aspects and concerns

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Abstract

Genetic engineering is a revolutionary new technology. Genetically-modified foods have the potential to solve many of the world's hunger and malnutrition problems. Genetically modified crops are being produced that are more resistant to pests, tolerant to herbicides and more nutritious. However, there are concerns about the safety of genetically modified crops. The concerns are that they may contain allergenic substances due to introduction of new genes into crops. The review of available literature indicates that the genetically modified crops available in the market intended for human consumption are generally safe; their consumption is not associated with serious health problems. However, because of potential for exposure of a large segment of human population to genetically modified foods, more research is needed to ensure that the genetically modified foods are safe for human consumption.

Keywords: GMO, biotechnology, India, genetics, crops

Introduction

Agriculture has been suffering from pest and disease infestation since its beginning, causing large, unpredictable losses in food production. Over the past decade, developments in modern biotechnology have expanded the scope of biological innovations by providing new tools for increasing crop yields and agricultural productivity. Genetic engineering of plants for resistance to pests and disease, by creating transgenic pest-protected plants, is one of the many tools for increasing food availability and security. Genetically modified crops have become increasingly important since they aim to improve crop yield even under environmental challenges. Genetic Engineering is a revolutionary new technology that is still in its early experimental stages of development. In genetic engineering, the intended gene is incorporated into the genome of the crop using a vector containing several other genes, including viral promoters, transcription terminators,

antibiotic resistance marker genes and reporter genes. Despite the concerns over GM food, the scope and number of GM crops planted each year continues to grow, and, interestingly, has made the adoption of GM seeds one of the most rapidly adopted farming technologies ever. According to the non-profit and science-based International Service for the Acquisition of Agri-Biotech Applications (ISAAA), the major biotech crops produced in the world include GM soybean, GM cotton, GM corn, and GM canola make up the majority of these crops [1] (Fig. 1). The field area for production of GM soybean has increased globally by 4.9% in 2009. In the case of maize, the field area planted with GM varieties increased by 10% to just under 42 million hectares and for GM cotton it increased by 3.2% to a total of 16 million hectares. However, every technological advance carries some risk of adverse effects. The same is true for GM food. Controversies continue to arise regarding their risks on health of humans and threat to biodiversity. An increasing number of scientists are warning that current gene-splicing techniques are crude, inexact, and unpredictable and therefore inherently dangerous. GM food might have the potential to be toxic and a threat to human health. Therefore, these food items need to be carefully examined before they can be used in the food supply, to ensure they are safe for human consumption.
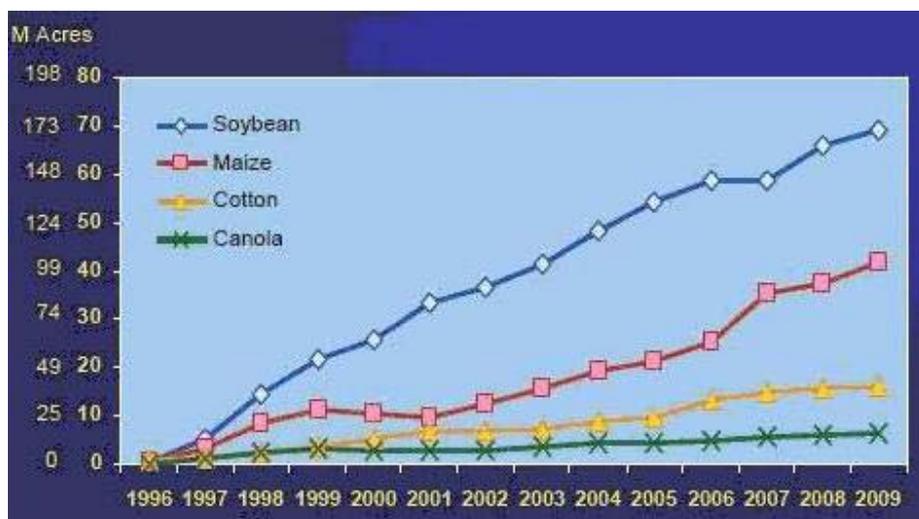

Figure 1. The global area of biotech crops from 1996 to 2009 by major crops.
Source: Clive James, ISAAA, 2010

Safety Assessment of Genetically Modified Food

WHO indicates that individual food items and their safety should be assessed in a case-by-case basis, and that it is not possible to make general statements on the safety of all GM food. The safety assessment of a genetically modified food is directed by the results of a comparison between the genetically modified food and its conventional counterpart. It follows a stepwise process aided by a series of structured questions. Factors taken into account in the safety assessment include:
- identity;
- source;
- composition;
- effects of processing/cooking;
- transformation process;

- the recombinant DNA (e.g. stability of insertion, potential for gene transfer);
- protein expression product of the novel DNA;
- effects on function;
- potential toxicity;
- potential allergenicity;
- possible secondary effects from gene expression or the disruption of the host DNA or metabolic pathways, including composition of critical macro-, micro-nutrients, anti-nutrients, endogenous toxicants, allergens, and physiologically active substances; and,
- potential intake and dietary impact of the introduction of the genetically modified food.

The above factors are particularly pertinent to the assessment of food derived from genetically modified plants [2].

Genetically Modified Food: How is it produced?

The term GM food refers to crop plants created for human or animal consumption using the latest molecular biology techniques. These plants are modified in the laboratory to enhance desired traits such as increased resistance to herbicides or improved nutritional content. Genetic modification of plants occurs in several stages:

1. An organism that has the desired characteristic is identified and the specific gene producing this characteristic is located and the DNA is cut off.

2. The gene is then attached to a carrier in order to introduce the gene into the cells of the plant to be modified. Mostly plasmid (piece of bacterial DNA) acts as a carrier.

3. Along with the gene and carrier a 'promoter' is also added to ensure that the gene works adequately when it is introduced into the plant.

4. The gene of interest together with carrier and promoter is then inserted into bacterium, and is allowed to reproduce to create many copies of the gene which are then transferred into the plant being modified.

5. The plants are examined to ensure that they have the desired physical characteristic conferred by the new gene.
6. The genetically modified plants are bred with conventional plants of the same variety to produce seed for further testing and possibly for future commercial use. The entire process from the initial gene selection to commercial production can take up to ten years or more.

Potential Advantages of GM Food

The world population has topped 6000 million people and is predicted to double in the next 50 years. Ensuring an adequate food supply for this booming population is going to be a major challenge in the years to come.

Table 1. Major GM Crop Producers in 2009.

Country	Area (million hectares)	Major GM crops produced
USA	64.0	Soybean, maize, cotton, canola, squash, papaya, alfalfa, sugar beet
Brazil	21.4	Soybean, maize, cotton
Argentina	21.3	Soybean, maize, cotton
India	8.4	Cotton
Canada	8.2	Canola, maize, soybean, sugarbeet
China	3.7	Cotton, tomato, poplar, papaya
Paraguay	2.2	Soybean
South Africa	2.1	Soybean, maize, cotton
Uruguay	0.8	Soybean, maize
Bolivia	0.8	Soybean
Philippines	0.5	Maize
Australia	0.2	Canola
Burkina Faso	0.1	Cotton
Spain	0.1	Maize
Mexico	0.1	Cotton, soybean
Chile	<0.05	Maize, soybean, cotton
Colombia	<0.05	Cotton
Honduras, Czech Republic, Portugal, Romania, Poland, Egypt, Slovakia	<0.05	Maize

Source: James Clive 2009

GM food promises to overcome the major constraints being faced in farming such as insect pest infestation and diseases which lead to substantial yield losses. In 2009, major biotech crop producing countries are shown in Table 1. With a leap from 15.8 to 21.4 million hectares, Brazil noted the largest increase. Burkina Faso was also noteworthy: after genetically modified cotton was grown for the first time in this African country on 8,500 hectares in 2008, field area increased to 115,000 hectares within one year. In China and Canada, the field area on which GM plants are grown decreased slightly. The nations growing GM plants on the largest field areas are the USA (64 million hectares), Brazil (21.4), Argentina (21.3), India (8.4) and Canada (8.2).

Although growth is expected to plateau in the industrialized nations, it is increasing in developing countries. Soybean, maize, cotton, and canola account for almost all commercial GMO production. GM plants are grown mainly in North and South America, but increasingly also in India, China and South Africa. The potential benefits of GM crops have been discussed below.

Pest Resistance

Common purpose of genetic modification of crops is to confer protection against insect pests. Importantly, this crop trait could substantially improve yields in the developing world where pest damage is rampant and reduce use of chemical pesticides. The soil bacterium *Bacillus thuringiensis* in Bt corn produces crystal proteins that are toxic to certain insects but generally harmless to vertebrates and non-lepidopteran insects [3]. A very well-known GM crop developed by Monsanto is Bt cotton that produces an insect control protein (Cry1Ac) derived from the naturally occurring soil bacterium, *Bacillus thuringiensis* subsp. *kurstaki* (B.t.k.). Production of the Cry1Ac protein in the cotton plant provides protection against key Lepidopteran insect pests including cotton

bollworm and pink bollworm [4]. The primary benefits of Bollgard cotton are reduced insecticide use, improved control of target insect pests, improved yield, reduced production costs, improved profitability, reduced farming risk and improved opportunity to grow cotton resulting in improved economics for the cotton growers [5, 6].

Herbicide Tolerance

For some crops, it is not cost-effective to remove weeds by physical means such as tilling, so farmers often spray large quantities of different herbicides to destroy weeds, a time-consuming and expensive process that requires care so that the herbicide doesn't harm the crop plant or the environment. Crop plants genetically-engineered to be resistant to one very powerful herbicide help prevent environmental damage by reducing the amount of herbicides needed. The crops are genetically modified to withstand the application of powerful herbicides using genes from soil bacteria. The herbicides to which the GM crops are tolerant are 'broad spectrum' weed-killers, which mean they can be sprayed over the entire field, killing all plants apart from the GM crop. Herbicide-tolerant crops include transgenes providing tolerance to the herbicides glyphosate or glufosinate ammonium. These herbicides kill nearly all kinds of plants *except* those that have the tolerance gene. Commonly known as Roundup, glyphosate is made by Monsanto and is the world's best selling herbicide. Monsanto has also created a strain of soybeans genetically modified to be not affected by their herbicide product Roundup ®. Another important benefit is that this class of herbicides breaks down quickly in the soil, eliminating residue carryover problems and reducing adverse environmental impacts [7].

Cold Tolerance

Unexpected frost can destroy sensitive seedlings. Certain crops are difficult to grow in particular climates for different reasons. For example, strawberries are not very frost hardy, which makes them difficult to grow in cold climates. Recently researchers have discovered that the arctic flounder produces an anti freeze protein to protect itself in arctic waters. Genetically engineered strawberries or soybeans expressing this anti freeze gene can protect themselves against the damaging effects of the frost, thereby sustaining under environmental constraints [8]. Moreover, an antifreeze gene from cold water fish has also been introduced into plants such as tobacco and potato. With this antifreeze gene, these plants are able to tolerate cold temperatures that normally would kill unmodified seedlings [9].

Nutrition

Malnutrition is common in third world countries where impoverished peoples rely on a single crop such as rice for the main staple of their diet. However, rice does not contain adequate amounts of all necessary nutrients to prevent malnutrition. Future GM crops could also have substantial direct nutritional or medicinal benefits to consumers. Crops could, for example, be genetically modified to produce micronutrients vital to the human diet. One type of such crop is "golden rice," genetically modified to produce beta-carotene, the precursor to vitamin A. According to WHO (2005) 45 and 122 countries have vitamin A deficiency of public health significance based on the prevalence of night blindness and biochemical vitamin A deficiency (serum retinol concentration <0.70 μ mol/l), respectively, in preschool-age children. Genetically modified 'golden rice' is one of the promising strategies to solve the vitamin A deficiency. This type of crop can be potentially beneficial among

Asian and African populations that suffer from malnutrition. Canola, too, can be genetically modified to enhance vitamin E content or to better balance fatty acids [7] while cereals on the other hand have been modified for specific starch or protein content [10]. Other efforts are aimed at modifying rice to increase the iron content in order to reduce anemia. Plant oils are also being modified to adjust cholesterol levels. GM food containing sweet proteins like thaumatin may be helpful to diabetics [11].

Pharmaceuticals

Medicines and vaccines often are costly to produce and sometimes require special storage conditions not readily available in third world countries. Research with transgenic plants offers a promise of large-scale production of safe, pure, and highly efficacious therapeutic proteins essential for the production of wide range of biopharmaceuticals including monoclonal antibodies (MAbs), enzymes, blood proteins, and new types of subunit vaccines. Researchers are working to develop edible vaccines in tomatoes and potatoes. These vaccines will be much easier to ship, store and administer than traditional injectable vaccines. Food crops engineered to produce edible vaccines against infectious diseases would make vaccination more readily available to children around the world. Because of their palatability and adaptation to tropical and subtropical environments, bananas have received considerable research attention as a vehicle for vaccine delivery. Transgenic (i.e., GM) bananas containing inactivated viruses protecting against common developing-world diseases, such as cholera, hepatitis B, and diarrhea, have been produced [7]. Because they would produce only the necessary antigens, these types of vaccine-producing GM crops may be safer than traditional vaccines whose additional materials often cause harmful side effects [12].

Environmental Monitoring and Remediation

Not all GM plants are grown as crops. Soil and groundwater pollution continues to be a problem in all parts of the world. Plants such as poplar trees have been genetically engineered to clean up heavy metal pollution from contaminated soil [13]. Plant based environmental remediation has been widely pursued in recent years as a favourable clean-up technology and is an area of intensive scientific investigation. Transgenic plants have been proposed as a tool to detect and deal with environmental pollution [14]. Rugh [15] reported that many plant taxa possess remarkable natural abilities for metal phytoextraction or organic compound phytodegradation. Superior Phytoremediation species have been characterized at the physiological, biochemical, and molecular genetic levels to identify specific processes for further improvement via genetic manipulation. Toward this goal, *Arabidopsis thaliana* and *Tobacum nicotiana* have been engineered with non-plant transgenes to enhance phytoremediation effectiveness against such priority pollutants as organomercurials [16], trichloroethylene solvents [17] and nitroaromatic explosives [18]. In addition, plants could be engineered to produce industrial raw materials that are biodegradable (e.g., bioplastics) and thus reduce loading of non-degradable plastics in the environment. Heavy metal pollutants can also be managed through bioremediation using GM trees.

Potential Health Risks of GM Food

Along with potential benefits of genetic modification of plants there are known and unknown risks, as common to all technologies, old or new. Genetically modified crops raises questions in many people's minds about the safety or adverse health effects [19]. Some of the adverse effects

attributed to genetically modified crops in humans include new allergens in the food supply, antibiotic resistance, production of new toxins. These are being discussed in detail below.

Food Allergenicity
One of the major health concerns with GM food is its potential to increase the food allergies in the human population through the food chain. Food allergies are adverse reactions to an otherwise harmless food or food component that involves an abnormal response of the body's immune system to specific proteins in foods. The most common type of food allergy is mediated by allergen-specific immunoglobulin E (IgE) antibodies1. IgE-mediated reactions are known as immediate hypersensitivity reactions because symptoms occur within minutes to a few hours after ingestion of the offending food. The World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) [20] has described a hierarchical approach to evaluate the allergenicity of genetically modified foods or crops. The three main approaches that can be utilized to identify allergen sources include:

(1) amino acid sequence characterization,

(2) identification of the amino acid sequences that define allergenic epitopes to develop more precise sequence-screening criteria; and

(3) development of an animal model(s) that can recognize food allergens in a manner similar to that which occurs in human disease.

Other factors in determining potential allergenicity of modified gene products include molecular mass (the molecular mass of most known allergens is between 10,000 and 40,000 Da), heat and processing stability (labile allergens in foods that are ingested after cooking or undergo other processing before consumption are of less concern), pH and gastric juices (most allergens are resistant to gastric acidity and to digestive proteases), and prevalence in foods (for example, new proteins expressed in nonedible portions of plants are not a concern in terms of food allergy). There is a good correlation between the resistance of proteins to proteolytic digestion and their allergic potential [21]. According to Prescott *et al.* [22] the introduction of a gene expressing nonallergenic protein such as GM field pea, expressing alpha-amylase inhibitor-1, may not always result in a product without allergenicity. *Brassica juncea*, a GM plant expressing choline oxidase gene caused low IgE response in mice and a cross-reactive epitope search showed a stretch similar to Hev b 6 having some antigenic properties although according to Singh *et al.* [23] it had no allergenicity. As for Bt expressed in many crops, farm workers exposed to Bt pesticide may develop skin sensitization and IgG antibodies to the Bt spore extraction [24]. There was a widely reported case where a methionine-rich 2S albumin storage protein from Brazil nut was expressed in soybean in order to increase the methionine content for animal feed. The protein was subsequently shown to be an allergen, as are a number of related 2S albumins from other species. The plant breeding programme was, therefore, discontinued as it would be difficult to guarantee that the GM soya would not enter the human food chain. The introduction of novel proteins into foods such as GE corn variety modified to produce a Bt endotoxin, Cry9C [24] may elicit potentially harmful immunological responses, including allergic hypersensitivity [25, 26].

Antibiotic Resistance

When gene engineers splice a foreign gene into a plant or microbe, they often link it to another gene, called an antibiotic resistance marker gene (arm), that helps determine if the first gene has successfully spliced into the host organism. These arm genes might unexpectedly recombine with disease-causing bacteria or microbes in the environment or in the guts of animals or people who eat GM food. These new combinations may be contributing to the growing public health danger of antibiotic resistance-of infections that cannot be cured with traditional antibiotics, for example new strains of salmonella, e-coli, campylobacter and enterococci. German researchers have found antibiotic resistant bacteria in the guts of bees feeding on gene-altered rapeseed (canola) plants. A genetically engineered Bt corn variety from Novartis includes an ampicillin resistance gene [27]. Ampicillin is an antibiotic that is used to treat a variety of bacterial infections in humans and animals. A number of European countries have refused to allow the Novartis Bt corn to be grown because of concern that the ampicillin resistance gene might be transferred from Bt corn to bacteria, making ampicillin a far less effective antibiotic against bacterial infections. According to one prediction, alternative types of marker genes will be developed in approximately five years and no new transgenic crops using antibiotic resistance marker genes will appear on the market [28].

GE Superweeds and Superpests

Ecologically, transfer of an herbicide-resistance gene into a weed can convert it into a superweed. Pests and weeds will emerge that are pesticide or herbicide resistant, which means that stronger, more toxic chemicals will be needed to get rid of the pests. Herbicide resistant "superweeds" are already emerging. GE crops such as rapeseed (canola) have spread their herbicide-resistance traits to related weeds such as wild mustard plants. Lab and field tests also indicate that common plant pests such as cotton bollworms, living under constant pressure from GE crops, will soon evolve into "superpests" completely immune to Bt sprays and other environmentally sustainable biopesticides. This will present a serious danger for organic and sustainable farmers whose biological pest management practices will be unable to cope with increasing numbers of superpests and superweeds. In some crops such as *Medicago sativa*, *Brassica napus* and *Brassica rapa*, *Helianthus annuus* and *Oryzae sativa* that have some weed-like characteristics, their transgenic and novel traits could allow the crop itself to become weedier and invasive [29, 30]. Resistance to transgenic proteins by insect pests may possibly limit the duration that an insecticidal transgenic variety can be feasibly grown. For example, the diamond black moth, an important pest to Brassica crops worldwide, was the first documented pest to develop resistance to Bt toxins applied as microbial formulations in open field populations [31].

Adverse Effects on Non-Target Species

Transgenic crops that express insecticidal transgenes to control agricultural pests may also affect non-target organisms [32, 33]. Many environmentalists are concerned that the pesticidal gene product of the genetically modified crops might be toxic to non-target organisms that consume it; for example, the incorporation of Bt genes into crop plants for insect control. The adverse health effects of Bt endotoxins in non-target species have been reported [34]. They show a narrow range of toxicity that is limited to specific groups of insects, Lepidoptera, Coleoptera or Diptera—depending on the Bt strain. Plant species containing Bt genes have been tested to determine whether any alterations in this limited spectrum of toxicity occurs and no unexpected results were reported [35, 36]. Concern has been expressed about the potential toxicity of the Bt toxin in corn pollen to the

monarch butterfly because initial laboratory studies showed increased mortality in larvae [37]. However, Sears *et al*. [38] believed that it is unlikely that a significant risk to those butterflies exists in the field.

Increase in Antinutrients

The insertion of a new gene can sometimes lead to increase in existing levels of anti-nutrients, some of which cannot be reduced with heat treatment [39]. One of the most widely available commercial GM products, glyphosate-resistant Roundup Ready soybean, may display an increase in anti-nutrients [40]. Heat-stable anti-nutrients such as phytoestrogens, glucinins, and phytic acid were also found to cause infertility problems in sheep and cattle [41], allergenic reactions and binding to phosphorus and zinc thereby making them unavailable to the animal respectively [42]. An increase in the anti-nutrient level should not be accepted since a GM food may be consumed as raw material.

Future Prospects

It is important to acknowledge that science and technology alone cannot fully mitigate the GM food debate, but science and technology can play important roles, and may open up new opportunities. Transgenic crops have the great potential to promote revolutionary change in agriculture industry, nutrition, and even medicine. Many novel techniques have already been used in the commercial production of GM crops. Plant raw materials such as fibres, oils and starch could be improved to allow more cost effective and environmentally benign processing by industry and entirely new industrial and therapeutic products could be produced in crops in substantial manner. With the revolution in genomics and molecular biology, modern biotechnology holds great promise for improving human health. Edible plant vaccines provide a promising example of a new strategy that combines innovations in medical science and plant biology to create affordable pharmaceutical products [43]. Coordinated multigene manipulation in plants for providing more durable transgenic techniques that can simplify the regulatory approval and can reassure the public about the safety and stability of GM products needs to be established and refined. Nutritionally-enhanced and biofortified crops offer the potential for addressing malnutrition but further work needs to be done to ensure that these crops can address multiple malnutritional deficiencies using the same crop.

Conclusion

Genetic engineering of crops is a new technology in its embryonic stage. It is essential to list any and all concerns about commercializing genetically modified food. Genetically-modified food has the potential to solve many of the world's hunger and malnutrition problems and to help protect and preserve the environment by increasing yield and reducing reliance upon chemical pesticides and herbicides. While the environmental, health and economic risks of GM crops should be carefully studied before full-scale adoption, the types of GM crops that are already available have thus far largely proven to be beneficial to agriculture and even to the environment. Despite opposition, the future looks bright for many GM crops and being able to successfully track and assess them will likely mitigate the GM food debate. Overall, there is increasing evidence to back up the argument that GM technologies have not lived up to the promises made by the biotech industry. New possibilities for many types of GM food could be the future. Agricultural innovation might finally move beyond providing commodity crops and fulfill the early promises that GM food will help feed the hungry and malnourished of our growing world.

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