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GENETICALLY MODIFIED PLANTS : BENEFITS AND ENVIRONMENTAL PROBLEMS

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ABSTRACT

The major goal of this review is to assess food risks of the introduction of genetically modified (GM) crops. The author analyzes the properties of the several classes of target proteins used in the transgenic constructions and discusses the problems that arise due to the lethal action of GM crops, the horizontal transfer of the transgenic constructions, in other traditional organisms, and their instability. Particular consideration is given to elevated risks of using the GM plant varieties on human health and various environmental risks associated with their introduction in field conditions. The authors emphasizes the requirement for assessing in detail all hypothetic risks in each particular case of cultivating GM varieties; as a control, such assessment must involve a comprehensive comparison with the conventional parental forms. A detail studies are required to assess the potential environmental risks of GM crops even though the technology promises many benefits. Further we need more and precise testing methods before making GM foods available for human consumption.

KEY WORDS: GM plants, Bt gene, Gene flow, Environmental risk.

INTRODUCTION

GM plants are widely grown all over the world, but many constraints still tend to discourage their commercial use in the field condition (Saleh-Lakha and Glick, 2005). Potential risks suggested to be associated with the use of GM are unexpected gene effects, allergenic potential, antibiotic resistance, gene flow. GM feed safety is presently evaluated by adopting the concept of GM substantial equivalence, by comparison with non-GM isogenic crops. Comparison is based on a wide spectrum of chemical components and on livestock performance. From the available experimental data, currently utilized GM plants appear safe and show no effects on animals or animal products. Hence, although they potentially exist, safety risks caused by the use of GM plants appear to be so low as be negligible in comparison with their potential benefits, if appropriately designed. GM plants represent a valuable option for future breeding, to increase yield while reducing the use of pesticides, improve plant adaptation to unfavourable environments, and produce better quality crops, also from a nutritional point of view. Nonetheless, GM crops are novel foods and the assessment of their safety using a scientific sound approach seems essential to protect the environment, as well as the health of humans and livestock.

According to the information reported by the WHO, the GM products that are currently on the international market have all passed risk assessments conducted by national authorities. These assessments have not indicated any risk to human health. In spite of this clear statement, it is quite amazing to note that the review articles published in international scientific journals during the current decade did not find, or the number was particularly small, references concerning human and animal toxicological/health risks studies on GM foods. In this paper, the scientific information concerning the potential toxicity of GM/transgenic plants using the Medline database is reviewed. Studies about the safety of the potential use of potatoes, corn, soybeans, rice, cucumber, tomatoes, sweet pepper, peas, and canola plants for food and feed were included. The number of references was surprisingly limited. Moreover, most published studies were not performed by the biotechnology companies that produce these products. This review can be concluded raising the following question: where is the scientific evidence showing that GM plants/food are toxicologically safe?

STATUS OF DEVELOPMENT OF GM FOOD CROPS IN INDIA AND ABROAD

Fourteen food crops have been approved for contained limited field trials in India are mentioned in Table 1. The trials are being conducted by both public and private sector institutions and the target traits include insect resistance, herbicide tolerance, viral and fungal disease

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resistance and stress tolerance. Worldwide growing of various GM crops cultivation is:

GM foods abroad:

1. US : Corn, Soyabean and Sugar beet.
2. Canada: Corn and Sugar beet.
3. China: Rice, Soyabean and Potato.

GM foods in India:

1. Bt Cotton
2. Bt Brinjal (Controversial).

GM foods under development in India.

1. Transgenic Rice
2. Transgenic Tomato

MAKING A GENITICALLY MODIFIED (GM) PLANTS

GM plants can be defined as organisms in which the genetic material (DNA) has been altered in a way that does not occur naturally. The technology is often called "modern biotechnology" or "gene technology," sometimes also "recombinant DNA technology" or "genetic engineering." It allows selected individual genes to be transferred from one organism into another, also between non-related species. Such methods are used to create GM plants which are then used to grow GM food crops.

As it turns out, nature has its own biotechnologist called *Agrobacterium tumefaciens* which induces the growth of tumours on woody plants. These tumours are engineered by *A. tumefaciens* to produce a special food for the bacteria (opines) that plants normally cannot make. These tumours arise from a unique bacterial transformation mechanism involving the Ti-plasmid which coordinates the random insertion of a subset of its DNA (t-DNA) containing opine synthase genes into a plant chromosome. By replacing portions of the t-DNA sequence with genes of interest (such as Cry), researchers have been able to harness this transformational mechanism and confer new traits to many flowering

Figure 1. An insect eating the cotton leaf.

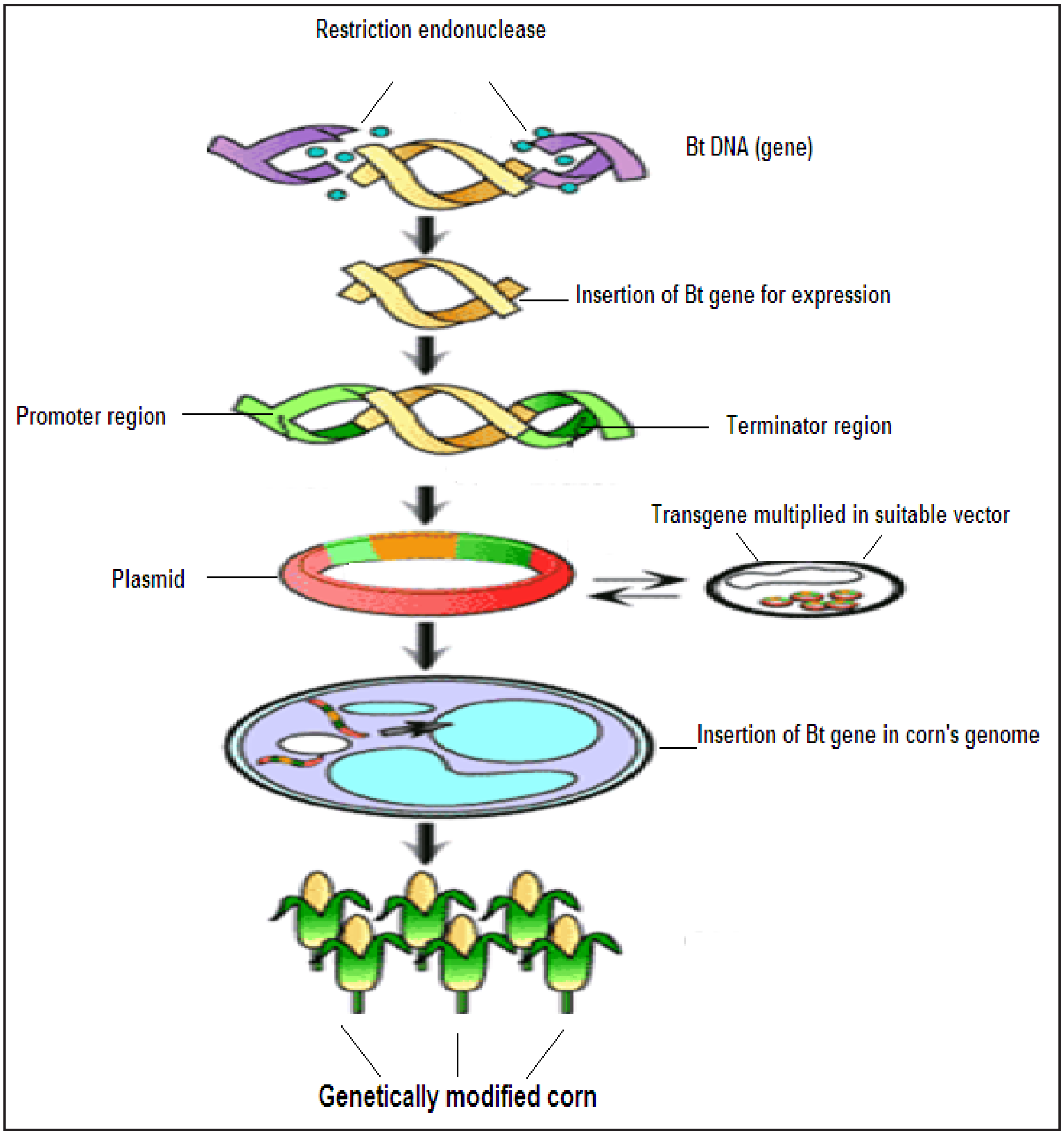


Figure 2. General schematic diagram showing genetically modified (GM) crop production.

plants including grasses such as corn7 and rice. Cry-transformed corn varieties, called 'Bt corn', produce sufficient levels of Cry proteins to provide an effective measure of resistance against ECB and are now widely grown in North America. A general schematic diagram showing genetically modified (GM) crop production has been presented in Figure 1.

GM CROPS (BT CROPS) AND PEST RESISTANCE

Bt corn, a GM crop, has been both the poster-child and thorn-in-the-side of the plant biotechnology industry from the late 1990's to present. There are several versions of this transgenic crop that each have a gene from an insect pathogen, *Bacillus thuringiensis* (Bt), which encodes a protein toxic to the European corn borer (ECB), an insect pest that eats and destroys corn stems (Figure 2). Bt corn has proven effective in reducing crop damage due to ECB, yet public opposition to Bt corn has escalated amid fears of human health and environmental risks associated with the production and consumption of Bt corn.

HISTORY OF BT

Bt corn draws its humble origins from France, where in 1938 *Bacillus thuringiensis* bacteria was grown in large quantities and sprayed on corn crops to prevent ECB damage. Artificial selection of Bt strains has led to the successful targeting of many insect pests. Because no toxic effects of Bt on humans have been detected in its seventy years of use, it is now considered an acceptable pest control measure for the organic food industry. To this day, Bt is an important part of many integrated pest management strategies. The success of the Bt spray has been limited because the bacteria cannot survive for very long on the plant's surface. Bt is particularly ineffective at controlling ECB because these insect live

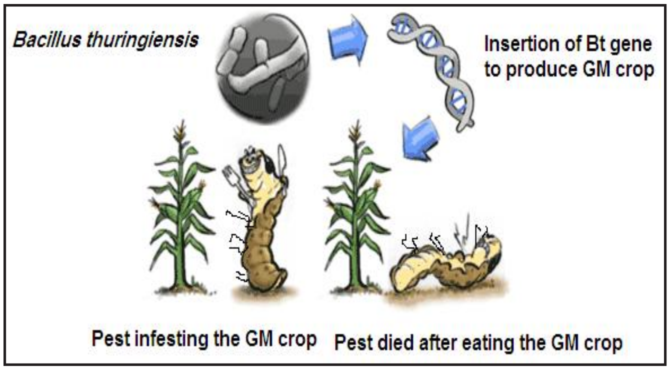


Figure 3. Genetically modified (GM) corn after the insertion of a gene from the *Bacillus thuringiensis,* corn becomes resistant to pest and kills the pest.

most of their larval life inside the corn stem, not on the surface: sprays are only effective when the insects are starting its journey into the stem. Thus, a means of penetrating corn tissue with Bt is required to offer long-term anti-feeding measures against tunneling insects such as ECB. Some facts about Bt and Bt-toxin are:

- *Bacillus thuringiensis* (Bt) – common soil borne bacterium.
- Produces proteins ("crystal proteins", Cry) that selectively kill certain groups of insects.
- Stomach toxins, must be ingested to kill.
- Protein binds to receptors in intestines and insect stops eating.
- Used in granular or liquid form > 30 years as a pesticide.
- Many (> 60) different Cry proteins and effective against different insects.

BT GENE AND MECHANISM OF BT TOXICITY

Researchers investigated how this bacterium kills particular insects and discovered that Bt has two classes of toxins; cytolysins (Cyt) and crystal delta-endotoxins (Cry). While Cyt proteins are toxic towards the insect orders Coleoptera (beetles) and Diptera (flies), Cry proteins selectively target Lepidopterans (moths and butterflies). As a toxic mechanism, Cry proteins bind to specific receptors on the membranes of mid-gut (epithelial) cells resulting in rupture of those cells. If a Cry protein cannot find a specific receptor on the epithelial cell to which it can bind, then the Cry protein is not toxic. Bt strains will have different complements of Cyt and Cry proteins, thus defining their host ranges. The genes encoding many Cry proteins have been identified providing biotechnologists with the genetic building blocks to create GM crops that express a particular Cry protein in corn that is toxic to a particular pest such as ECB yet potential safe for human consumption.

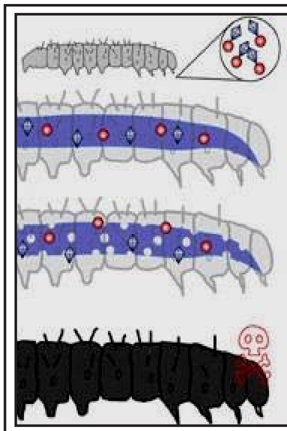
INTRODUCTION OF BACILLUS THURINGIENSIS-GM BT CROPS

Bt corn, Bt cotton, and Bt potatoes etc. are GE plants that incorporate Bt, a natural toxin from the bacterium *Bacillus thuringiensis* that is deadly to many pest species but has low toxicity for most benign organisms, beneficial predators, and humans. The main idea behind GE Bt crops is that they eliminate the need for conventional farmers those who have traditionally used chemical pesticides—to apply insecticides to their crops, which is better for the environment and cheaper for the farmer. But Bt is not a new approach dreamed up in the bowels of one the agribusiness corporations. Bt spray has been used for decades for pest control and has been a particularly important tool for organic farmers, who aren't allowed to use the highly toxic arsenal of chemical pesticides used by "conventional farmers." What's new is that the genetic engineers have figured out how to embed the genetic characteristics of the Bt toxin directly into some plants primarily corn, cotton, and potatoes so that they become naturally resistant to pests.

In the past, Bt has been applied topically to plants to control pests, but as with any other pesticide, rain eventually washes it off and the Bt spray must be applied again, running up the farmer's costs and labor. Since the Bt corn and cotton have the Bt toxin embedded as part of the genetically engineered plant's cells, the wash-off problem is eliminated.

THE PROBLEMS WITH GM CROPS

All that sounds good in theory, but there is a big problem with Bt crops. Prior use of Bt by farmers has always been on an as-needed basis and in combination with other insect control techniques. This intermittent use has prevented insects from developing resistance to Bt. With Bt corn and cotton, the insects are constantly exposed,



A. Insect eats *Bt* crystals and spores.
B. The toxin binds to specific receptors in the gut and the insects stops eating.
C. The crystals cause the gut wall to break down, allowing spores and normal gut bacteria to enter the body.
D. The insect dies as spores and gut bacteria proliferate in the body.

Bt action is very specific. Different strains of *Bt* are specific to different receptors in insect gut wall. *Bt* toxicity depends on recognizing receptors, damage to the gut by the toxin occurs upon binding to a receptor. Each insect species possesses different types of receptors that will match only certain toxin proteins, like a lock to a key.

It is because of this that farmers have to be careful to match the target pest species with a particular *Bt* toxin protein which is specific for that insect. This also helps the beneficial insects because they will usually not be harmed by that particular strain of *Bt*.

Figure 4. Steps involved how the insect eat the Genetically modified (GM) crop after the insertion of a gene from the *Bacillus thuringiensis*, and get killed.

and it is thus inevitable that insect will develop resistance to Bt. (Resistance is not a phenomenon specific to Bt insects develop resistance to regularly applied chemical pesticides, too.

There are a couple of aspects to the development of resistance in genetically engineered Bt crops. First, the obvious way: Insects eating Bt crops are constantly being exposed to the pesticide and, over time, subsequent generations of the insects will eventually become resistant. But there is another factor: Because crops grow unevenly in nature's differing conditions and because expression of the Bt gene is not uniform throughout the plant, some pests will get a "sub-lethal dose" of Bt toxin, which will facilitate the development of resistance in the same way that pathogenic bacteria become resistant when a patient fails to complete the full course of an antibiotic.

BENEFITS OF GE CROPS

With the rapid growth in the global population making it increasingly difficult to provide sufficient amounts of food (Saleh-Lakha and Glick, 2005), one potential solution is the use of GE crops, which might support starving populations through increased crop yield. However, the launch of GM foodstuffs has been impeded, in particular, by the reluctance of different regional jurisdictions to permit the application of GM plants (Moloney and Peacock, 2005). The various other possible benefits of GM crops over the traditional crops may be as followings:

- No use of pesticides.
- Better to insect/pest resistance.
- Can be grown in stress environments.
- Drought resistance.
- Germinated earlier.
- More test and flavour.
- No repetition of undesirable and useless nutrients.
- Herbicide resistance (Round-up Ready).
- Increased nutrient value (Golden Rice).
- Produce drugs (Vaccines).
- Alter properties of crop (polyester cotton).

HUMAN HEALTH AND ENVIRONMEN-TAL RISKS

Table 1: GM crops under development and field trials in India.

GM Crop	Institute/Organization	Gene used
Brinjal	IARI, New Delhi MAHYCO, Mumbai	*cry1Ab* *cry1Ac*
Cauliflower	MAHYCO, Mumbai Sungrow Seeds Ltd., New Delhi	*cry1Ac* *cry1Ac*
Tomato	MAHYCO, Mumbai NCPGR	*cry1Ac* *OXDC*
Sorghum	MAHYCO, Mumbai	*cry1Ac*
Cabbage	Sungrow Seeds Ltd., New Delhi	*cry1Ac*
Chickpea	ICRISAT, Hyderabad	*cry1Ac, cry1Ab*
Groundnut	ICRISAT, Hyderabad	*IPCVcp, IPCV replicase*
Maize	Monsanto, Mumbai	*CP4 EPSPS*
Mustard	IARI, New Delhi NRCWS, Jabalpur TERI, New Delhi UDSC, New Delhi	*CodA, osmotin bar, barnase,* *barstar Ssu-maize Psy, Ssu-tpCrtI* *bar, barnase, barstar*
Okra	MAHYCO, Mumbai	*cry1Ac*
Pigeonpea	ICRISAT, Hyderabad MAHYCO, Mumbai	*cry1Ab + SBTI* *cry1Ac*
Potato	CPRI, Simla NCPGR, New Delhi	*cry1Ab* *Ama-1*
Rice	Directorate of Rice Research, Hyderabad Osmania University, Hyderabad IARI, New Delhi MAHYCO, Mumbai MKU, Madurai MSSRF, Chennai TNAU, Coimbatore	*Bacterial blight resistant, Xa-21, cry1Ab, gna gene, sheath blight resistant gna Bt, chitinase, cry1Ac and cry1Bcry1Aa* *cry1Ac chitinase, B-1,3-glucanase, osmotin genes from mangrove species chitinase*

Source: Department of Biotechnology, Government of India

The promise of this technology has been largely overshadowed by concerns about the unintended effects of Bt corn on human health and the environment. Cry protein toxicity, allergenicity, and lateral transfer of antibiotic-resistance marker genes to the microflora of our digestive system threaten to compromise human health (Pusztai and Bardocz, 2005). Despite these alarming possibilities, the risks to human health appear small based upon what is known about the bacterial endotoxin, its specificity, and confidence in the processes of plant transformation and screening. The task of determining the levels of such risks, however, are immense. Human diets are complex and variable. How can we trace the acute or chronic effects of eating GM ingredients when they are mixed in with many other foods that may also present their own health hazards? It is even more complicated to determine the indirect risk of eating meat from animals raised on transgenic crops. These tests take time, and the results of clinical trials are not always clear-cut. It will likely take decades before we can know with any certainty if Bt corn is as safe for human consumption as its non-GM alternatives.

We currently know very little about the actual ecological risks posed by Bt corn. Bt corn may be toxic to non-target organisms, transgenic genes may escape to related corn species, and ECB and other pests may become resistant to Cry proteins. The alleged effect of Bt corn pollen on Monarch butterfly larvae has rocketed to the front pages of major newspapers around the world. Some research has shown that Monarch butterfly larvae fed their normal diet of milkweed leaves suffer a significant decline in fitness when those leaves are dusted with Bt corn pollen. The methodology of this experiment, however, has been harshly criticized by members of the scientific community.

The threat of Cry gene escape into wild populations has been substantiated by the discovery that artificial DNA from transgenic corn has been detected in traditional corn varieties in remote areas of Mexico. While few contest that such transgenes are present in the local corn races of Mexico, there is still no evidence to suggest that these genetic constructs are "escaping" to become established in local corn races. We are limited to an educated guess as to the likelihood and speed of such genetic pollution.

MAJOR ECOLOGICAL RISKS ASSOCIATED WITH GM CROP

Conventional breeding allows mixing and recombination of genetic material between species that share a recent evolutionary history. On the other hand, genetic engineering is an imprecise, haphazard technology and is completely different from traditional plant breeding. With alarming regularity, biotechnology companies have demonstrated that scientists cannot control where genes are inserted and cannot guarantee the resulting outcomes. Unexpected field results highlight the unpredictability of the science, yet combinations previously unimaginable are being field tested and used commercially.

The nature of the process of genetic engineering produces unpredictable effects at the genetic and cellular level, which will inevitably have impacts at the ecological level. The followings are some major ecological concerns related to the introduction of GM crop in field conditions.

- **Potential health hazards:** Several studies on Bt crops in particular and GM crops in general show that there are many potential health hazards in foods bio-engineered in this manner. GM-fed animals in various studies have shown that there are problems with growth, organ development and damage, immune responsiveness and so on. It has also been shown from studies elsewhere that genes inserted into GM food survive digestive processes and are transferred into the human body.They are known to have transferred themselves into intestinal bacteria too. Bt toxin had caused powerful immune responses and abnormal cell growth in mice.It has also been shown that all the Cry proteins in Bt crops have amino acid sequence similar to known allergens and are hence potential allergens.
- **Origin of super weeds:** Research suggests that bees may be important pollen vectors over a range of distances and farm-to-farm spread of oilseed rape transgenes will be widespread. Pollen can also travel for miles in the wind and integrate its DNA into the genome of conventional plants. Genes from GE crops can spread to wild plants and native species, resulting in herbicide resistant superweeds. The traditional weed then becomes a stronger "superweed." This outcrossing has started to produce superweeds that are resistant to a wide range of herbicides.
- **Loss of biodiversity:** With development of transgenic crops, traditional varieties may be eliminated as farmers will grow only GM crops to obtain the highest yields for commercial production. Bt (*Bacillus thuringiensis*) toxins are becoming ubiquitous, highly bioactive substances in agroecosystems. Bt crops are pumping out huge amounts of toxin from all tissues throughout the growing season, from germination to senescence. Most non-target herbivore insects, although not lethally affected, ingest plant tissue containing Bt protein which they can pass on to their natural enemies. The spread of transgenes into the wild and the effect this will have on biodiversity may be especially severe in less developed countries where native varieties of agricultural crops exist.
- **Loss of soil fertility:** Many crops are engineered with the Bt toxin in order to resist infestation from insects. Yet root exudates from these plants release the toxin into the soil. This stimulates major changes in soil

biota that could affect nutrient cycling processes and reduce soil fertility. Scientific studies have shown that Roundup Ready soybeans are toxic to earthworms, beneficial insects, birds and mammals (in addition to destroying the vegetation on which they depend for food and shelter). A study of University of Missouri revealed that Roundup Ready soybeans receiving glyphosate at recommended rates had significantly higher incidence of *Fusarium* on roots compared with soybeans that did not receive glyphosate.

- **Effects on non-target insects:** The Bt toxin has been shown to be lethal to non-target organisms such as Monarch butterflies, lacewings and ladybird beetles. The issue is broader than whether Bt toxin produced by genetically modified crops imperils beneficial insects. The real issue is that a strategy to establish expression of an insecticidal compound in large-scale crop monocultures and thus expose a homogeneous sub-ecosystem continuously to the toxin can cause irreparable damage to natural habitats forever
- **Sustainable agriculture and organic farming threatened:** The entire future of organic farming is being threatened because pollen transfers by insects and the wind from GE crops to organic farms. Cross pollination can move transgenes into the crops so that, against their intentions, farmers are growing GE crops. Bt microbes are applied by organic farmers as a surface agent (when one is absolutely necessary) and will become ineffective as an important biological insect control tool. Transgenes may cause significant damage to that genetic diversity, and commercialization of a few varieties of patented seeds will also erode this vital heritage. "Terminator" systems designed to protect seed companies' profits by ensuring that farmers can't save seed (the succeeding crop will be sterile) are a further step away from sustainable agricultural practices and respect for the diversity of our agricultural heritage.
- **GM crops provoke immune reactions:** Research showed significant immune system changes in mammals fed Bt corn. GM soy and corn each contain two new proteins with allergenic properties (Irina, 2006). GM soy has up to seven times more trypsin inhibitor-a known soy allergen and skin prick tests show some people react to GM, but not to non-GM soy. Perhaps the US epidemic of food allergies and asthma is a casualty of genetic manipulation.

GM CROPS AND CONTROVERCIES

In the past few weeks, genetically modified crops have again been at the forefront of controversy involving contamination of rice and grass varieties. Environmentalists, politicians, and scientists have long feared that the introduction of genetically modified seeds and plants could cause detrimental effects from "genetic pollution," which occurs when an engineered gene enters another species of crop or wild plant through cross-pollination (Smith, 2007). Plant ecologists, entomologists, and population geneticists have approached the GM crop technology and its vast application with caution based with following controversies:

- **Safety**
  - Potential human health impacts, including allergens, transfer of antibiotic resistance markers, unknown effects.
  - Potential environmental impacts, including: unintended transfer of transgenes through cross-pollination, unknown effects on other organisms (e.g., soil microbes) and loss of flora and fauna biodiversity.
- **Access and Intellectual Property**
  - Domination of world food production by a few companies.
  - Increasing dependence on industrialized nations by developing countries.
  - Biopiracy, or foreign exploitation of natural resources.
- **Ethics**
  - Violation of natural organisms' intrinsic values
  - Tampering with nature by mixing genes among species.
  - Objections to consuming animal genes in plants and vice versa.
  - Stress for animal.
- **Labeling**
  - Not mandatory in some countries (e.g., United States.
  - Mixing GM crops with non-GM products confounds labeling attempts.
- **Society**
  - New advances may be skewed to interests of rich countries.

GENETICALLY MODIFIED CROPS IN INDIA: THE BT BRINJAL CONTROVERSY

This case discusses the introduction of Bt Brinjal in India in the backdrop of the controversy surrounding genetically modified (GM) crops in India. Monsanto Holdings P Ltd, a US based multinational agricultural biotechnology corporation that promoted GM crops in India through Mahyco-Monsanto Biotech (a 50:50 joint venture between Monsanto and Maharashtra Hybrid Seeds Company) found itself in the center of this debate.

India, as a party to the Convention on Biodiversity and having ratified the Cartagena Protocol (CP) is committed to the safe handling of living modified organisms (LMOs) or GMOs. CP provides a broad framework on bio-safety especially focusing on transboundary movements of GMOs and also covers seeds that are meant for intentional release into the environment, as well as those GMOs that are intended for food, feed or used in food processing.

Bt cotton was the first transgenic crop to be released in India. After its introduction in the year 2002, there has been a lot of controversy surrounding Bt cotton. Its performance, impact on the environment, biodiversity and health of cattle has been widely debated. With the regulatory body for approving GM crops in India, Genetic Engineering Approval Committee (GEAC), announcing its approval for large scale field trials for Bt Brinjal in September 2007, some analysts opined that Bt Brinjal would have a significant economic impact on farmers while some raised doubts on its safety and environmental implications. The various issues related to GM crops may be as:

- Analyze the business environment for GM crops in India
- Study the regulatory environment pertaining to GM crops in India.
- Understand the bio-safety protocol and its necessity and relevance to developing countries like India.
- Understand bio-safety governance in India: its accuracy and lacunae.
- Discuss the role of activists and researchers in influencing policies.

STEPS FOR ANALYSIS OF ENVIRON MENTAL RISK ASSESSMENT OF GMOs

National Environmental Research Institute (NERI) has carried out research and ad-visory tasks concerning environmental risk assessment of genetically modified organisms (GMOs), including plants and micro-organisms for deliberate release and for contained industrial use. The research includes po-pulation dynamics, gene transfer, food chain effects and possib-le consequences for non-target organisms in agricultural as well as non-agricultural ecosystems. Ecological modelling is an integrated part of the research.

The six steps in the analysis of environmental risk assessment of genetically modified organisms as outlined by the guidance notes on the deliberate release into the environment of genetically modified organisms may be as:

1. Identification of characteristics which may cause adverse effects.
2. Evaluation of the potential consequences of each adverse effect, if it occurs.
3. Evaluation of the likelihood of the occurrence of each identified potential adverse effect.
4. Estimation of the risk posed by each identified characteristics of the GMOs.
5. Application of management strategies for risks from the deliberate release or marketing of GMOs.
6. Determination of the overall risk of the GMOs.

CONCLUSIONS

In broad terms, the dynamic diffusion models indicate that future growth of Bt crops will be slow or even become negative, depending mainly on the infestation levels of Bt target pests. If the genes inserted in GE crops do not function as intended, crop losses may result. GE varieties have also demonstrated new susceptibility to pests and diseases, for unknown reasons. A GE plant to resist insects also has an impact upon pest populations, since troublesome new pests that require heavy use of insecticides can emerge as a result. With the regulatory body for approving GM crops in India, Genetic Engineering Approval Committee (GEAC), announcing its approval for large scale field trials for Bt brinjal, some analysts opined that Bt brinjal would have a significant economic impact on farmers while some raised doubts on its safety and environmental implications. GE crops have repeatedly failed to perform as intended in the field and have given rise to many ecological problems such as genetic pollution, loss of biodiversity and sustainable agriculture development etc. Further studies are needed to assess the potential environmental risks of GM crops even though the technology promises many benefits. We need more and better testing methods before making GM foods available for human consumption.

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