Genetically Modified Crops: Food Security and Issues

A DISSERTATION

By

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Everything may wait but agriculture can not…

- Jawaharlal Nehru

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Place : IIPA, New Delhi

Dated:

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CERTIFICATE

I have the pleasure to certify that Dr. Praveen Kumar Mehrotra has pursued his research work and prepared this dissertation titled **'Genetically Modified Crops: Food Security and Issues'** under my guidance and supervision. The dissertation is the result of his own research and to the best of my knowledge no part of it has earlier comprised of any other monograph, dissertation or book. This is being submitted to the Panjab University, Chandigarh for the degree of Master of Philosophy in Social Sciences in partial fulfilment of the requirement for the Advanced Professional Programme in Public Administration (APPPA) of Indian Institute of Public Administration (IIPA) New Delhi.

I recommend that the dissertation of Dr. Praveen Kumar Mehrotra is worthy of consideration for the award of M Phil Degree of Panjab University, Chandigarh.

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SELF - DECLARATION

I declare that the dissertation titled **'Genetically Modified Crops: Food Security and Issues'** for the award of Master of Philosophy Degree in Social Sciences of Panjab University, Chandigarh is original research work and that this work or a part thereof has not been submitted for the award of any degree or diploma of either this or any other University.

Place : IIPA, New Delhi

Dated:

Dr. Praveen Kumar Mehrotra

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ACRONYMS AND ABBREVIATIONS

Bt	*Bacillus thuriengiensis*
CAB	Cotton Advisory Board
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CPMB	Centres for Plant Molecular Biology
Cry	Crystalline protein
DBT	Department of Biotechnology
DLC	District Level Committees
DNA	Deoxyribonucleic acid
EU	European Union
GEAC	Genetic Engineering Approval Committee
GHG	Green House Gases
GM	Genetically modified
GMO	Genetically Modified Organism
HT	Herbicide tolerance
IADP	Intensive Agriculture District Programme
IARI	Indian Agricultural Research Institute
IBSC	Institutional Biosafety Committees
ICAR	Indian Council of Agricultural Research
IPRs	Intellectual Property Rights
IR	Insect Resistant
MAHYCO	Maharashtra Hybrid Seeds Company Ltd.
MDG	Millennium Development Goal

Mha	Million hectares
NCPGR	National Centre for Plant Genome Research
NGO	Non Governmental Organisation
PPP	Public Private Partnership
rDNA	Recombinant deoxyribonucleic acid
RCGM	Review Committee on Genetic Manipulation
RDAC	Recombinant DNA Advisory Committee
SBCC	State Biosafety Coordination Committees
TMV	Tobacco Mosaic Virus
UK	United Kingdom
UN	United Nations
USA	United States of America
WHO	World Health Organisation

1. Introduction

Before independence, Indian history was replete with famine, drought and food shortages. Between 1770 and 1880, as many as 27 food scarcities and famines were recorded. At least 20 million lives were lost in India famines that had struck since 1850. The big gap between minimum requirement and supply had continued even after independence. Till the 1960s, Indian agriculture was not sufficiently able to meet domestic requirements and the country had to rely on food grain imports.

1.1 The Green Revolution

Realising the disastrous consequences of the growing gap between the rates of growth of population and food production, a vigorous **'grow more food'** campaign was launched. The key goal of economic planning shifted to attaining self-sufficiency. The First Five-Year Plan, following food imports in 1951, gave maximum importance to the growth of agriculture. Among the measures initiated in the 1950s to stimulate food grain production were land reforms, irrigation, fertiliser production, strengthening of research and the organisation of a national farm extension service. Consequently, increased harvests in the mid-1950s relieved the economy.

In 1961, the government launched the **Intensive Agriculture District Programme (IADP)** to enhance productivity in the irrigated areas. Although the aim was to introduce improved seed along with a package of agronomic practices to take advantage of the available irrigation, the programme did not come up to expectations for want of high-yielding varieties of wheat.

The tall Indian wheat varieties did not provide an economic response to the application of chemical fertilisers and irrigation water, which agricultural scientists were desperately looking for. These had a tendency to fall down or lodge when fertilisers were applied, as a result of which the yields stagnated at less than one tonne per hectare. Even though breeding for improved non-lodging wheat varieties was initiated in the '50s, it did not meet with much success.

The missing link was provided by Dr Norman Borlaug, who was then working with CIMMYT in Mexico. A few dwarf wheat strains of spring wheat that he sent to the Indian Agricultural Research Institute in New Delhi looked impressive. In the next two to three years, a wide range of dwarf material was tested under the All India Wheat Research Project. In August 1964, the then Professor and Head of Department of Plant Breeding and Genetics at the IARI, Dr M S Swaminathan, who later emerged as the architect of India's Green Revolution, proposed the launching of a National Demonstration Programme in farmers' fields. This would verify the results obtained in research plots and introduce farmers to new opportunities opened up by semi-dwarf varieties for considerably improving the productivity.

"When small farmers, who with the help of scientists organised the National Demonstration Programme, harvested over 5 tonnes of wheat per hectare, its impact on the minds of other farmers was electric. The clamour for seeds began and the area under high-yielding varieties rose from 4 hectares in 1963-64 to over 4 million hectares in 1971-72. A small government programme became a mass movement." Subsequently, the government imported 18,000 tonnes of semi-dwarf wheat from Mexico in 1966 to be distributed in time for immediate sowing by farmers in the northwestern regions.

The seeds of the Green Revolution were, therefore, truly sown in the mid-'60s. What followed next is already part of contemporary history. Wheat production rose to 17 million tonnes in 1968, an increase of 5 million tonnes over the highest of 12 million tonnes harvested in 1964. Then Prime Minister Smt. Indira Gandhi officially recorded the impressive strides in agriculture by releasing a special stamp entitled 'Wheat Revolution' in July 1968. The success of wheat was later replicated in rice. Productivity increases were also recorded in cotton, sugarcane, millets and oilseeds. Table-1 gives the trends of out put of food grain in India as published by the *Department of Food and Public Distribution* with figures in million tonnes (Datt and Sundharam, 2004). The initial rate of improvement of the Green Revolution was not sustained during 1985-90. The best areas had already been saturated with semi-dwarf wheat and rice. Further, yield increases were held back by water shortages, soil problems, and the emergence of new types of pest and disease.

1.2 Decline in Production

Thirty years after the dawn of the Green Revolution, Indian farmers are realising that their love affair with intensive agriculture is on the decline. Despite a bountiful monsoon for the tenth year in a row, harvests are not as

Table- 1

Trend of output of cereals and major food grains (figures in million tonnes).

Year	Cereals	Rice	Wheat	Coarse grains	Pulses
2001–02	199.48	93.34	72.70	33.37	13.37
2004–05	192.73	87.80	73.03	31.88	13.67

Source: Datt and Sundharam, 2004

plentiful as expected. However, with no let-up in the ever-increasing rise in population, Indian agriculture is once again at the crossroads. Alarm bells have been ringing for quite some time. For nearly a decade, agricultural production has stagnated. The spectacular yield growth recorded in the post-Green Revolution years in Punjab and Haryana has receded into history.

Rapid fragmentation of land holdings is keeping pace with increasing population. In 1976-77, the average size of the holdings was estimated at 2 hectares, while in 1980-81, it came down to 1.8 hectares. Now, it stands at a mere 0.2 hectares. The total number of land holdings in 1981 was around 89 million; today these have crossed 100 million. By the turn of the century, the average land holding will come down to 0.11 hectares. It is quite obvious that with such small land holdings, Indian agriculture cannot adopt high-tech farm practices.

In 1995-96, food grain production slumped to minus 3.60 per cent. In 1997-98, it further declined to minus 3.70 per cent, the worst-ever since the heady days of the Green Revolution. Food grain production in the frontline agricultural states of Punjab, Haryana and western Uttar Pradesh, comprising the country's food bowl, has decelerated. Tamil Nadu, another Green Revolution area, is under tremendous strain from intensive cultivation. In Karnataka, the negative trend in yield levels of all food crops, barring cotton and sugarcane, are all too apparent. Farming in Karnataka can be clearly separated in two distinct classes, the 'creamy layer' of corporate agriculture occupying the fertile and irrigated areas, and the remaining low productive tracts at the mercy of the rains, constituting the tiny and small land holdings. Kerala too, picturesque and verdant with tropical forests, is passing through its worst-ever crisis on the food grain front.

1.3 Green, Gene and Evergreen Revolution

Out of 5.1 billion people in the developing world, 1.2 billion still suffer from poverty and starvation. Achieving food and nutritional security for the Indian masses will require a significant increase in daily intake of calories, protein, vitamins and minerals. The present nutritional gap represents a vast demand for more and better quality food.

Indians consume an average of 40 grams per day of horticulture products compared to a normal nutritional demand of 90 grams. As incomes rise, the domestic market for horticulture products is projected to increase by 60% over the next six years. Overall, there is scope for placing an additional 1 million acres under horticulture crops. This will generate demand for 100 new commercial hybrid seed production units in the country.

Sugar consumption in India has tripled over the last three decades and now exceeds 13 kg per person per year. Yet even current levels of consumption remain very low compared with those of other developing countries: 21 kg in Kenya, 31 kg in Argentina, 33 kg in Egypt, 44 kg in Brazil and 45 kg in Mexico.

Improvement of agricultural production and productivity as well as the future versatility of agricultural production are dependent on the

rational utilisation of emerging technologies. We stand at the convergence of an incredible array of new technologies, such as recombinant DNA technology, information technology and high throughput genomics, to enhance our understanding of the structure and function of the genomes and to apply this information for gene and evergreen revolution.

1.4 Biotechnology

The term `**biotechnology**' refers to any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for a specific use. Biotechnology, in the form of traditional fermentation techniques, has been used for decades to make bread, cheese or beer. It has also been the basis of traditional animal and plant breeding techniques, such as hybridization and the selection of plants and animals with specific characteristics to create, for example, crops which produce higher yields of grain. Modern biotechnology, meanwhile, employs advanced techniques such as genetic engineering or recombinant deoxyribonucleic acid (rDNA) technology whereby researchers can take a single gene from a plant or animal cell and insert it in another plant or animal cell to give it a desired characteristic, such as a plant that is resistant to a specific pest or disease.

1.5 Genetically Modified Organism (GMO)

In modern science, a Genetically Modified Organism (GMO) is that in which the basic genetic material (DNA) has been artificially altered or modified to improve the attributes or make it perform new functions. Common GMOs include agricultural crops that have been genetically modified for greater productivity or for resistance to pests or diseases e.g. Bt cotton, incorporating a gene from a bacterium *Bacillus thuriengiensis* effective against the American Bollworm, a major pest on cotton.

Application of GMOs in agriculture is primarily for the production of **'transgenic plants'** with higher yield and nutritional content, increased resistance to stress and pests.

1.6 Transgenic Plants

A transgenic plant contains a **gene or genes** of a **different species** which have been **artificially inserted** instead of the plant acquiring them through pollination.

Transgenic technology is similar to conventional breeding in terms of the objective of generating more useful and productive crop varieties containing new combination of genes, but it expands the possibilities by enabling introduction of useful genes not just from within the crop species or from closely related plants, but from a wide range of other organisms. It allows the transfer of one or more genes, in a controlled and predictable way than is achievable in conventional breeding. Transgenic crop plants can therefore incorporate the desired traits more quickly and more reliably than through conventional methods.

Several commercially important transgenic crops such as maize, soyabean, tomato, cotton, potato, mustard, rice etc. have been genetically modified and the following traits have been imparted:

Herbicide Resistance

Many effective broad-spectrum herbicides do not distinguish between weeds and crops, but crop plants can be modified to make them resistant to herbicides, so as to eliminate weeds more selectively. For example-GM cotton and soyabean resistant to herbicide RoundupTM have been developed. Genes that provide resistance to other herbicides such as sulfonyl ureas, gluphosinates etc. have also been identified and transferred to produce various transgenic plants.

Insect Resistance

Biotechnology has opened up new avenues for natural protection for plants by providing new biopesticides, such as micro-organisms, that are toxic to targeted crop pests but do not harm humans, animals, fish, birds or beneficial insects. One of the best known examples is that of commonly found soil bacterium Bacillus thuriengiensis. The spores of Bacillus thuriengiensis (Bt) contain a crystalline protein (Cry), which breaks down to release a toxin, known as delta-endotoxin, is highly toxic to lepidopteran larvae. Different Cry genes, also known as Bt genes have been identified, cloned and characterized. Effective gene constructs have made it possible to deliver these genes into plant tissues so that they are expressed at levels high enough to kill the insects. Bt cotton and maize which have increased resistance to boll worms have been developed and cultivated since 1996 globally.

Disease Resistance

Plants are susceptible to viral, bacterial and fungal diseases. Much progress has been made in evolving transgenic plants resistant to viruses. For example, expression of a gene that encodes the coat protein of tobacco mosaic virus (TMV) in transgenic tobacco plants has been shown to cause the plants to resist TMV infection. A number of other viral resistant plants species have been developed including papaya, squash and potatoes. Genetic engineering of crop plants for resistance to fungal and bacterial infections has been more difficult.

Produce Quality Improvement

Some of the value added transgenic crops developed via rDNA technology include tomato varieties exhibiting delayed ripening, transgenic potatoes with increased levels of starch, golden rice containing beta carotene to overcome vitamin A deficiencies, canola containing high levels of oleic acids and laurate, barley containing feed enzymes, and other vegetables and fruits with delayed ripening as well as modified flavour characteristics.

Resistance to Environmental Stress

In addition to the biological challenges to plant growth and development, crops plants need to cope up with abiotic stresses such as drought, cold, heat and soils that are too acidic or saline to support plant growth. While plant breeders have successfully incorporated genetic resistance to biotic stresses such as diseases into many crop plants through crossbreeding, their success at creating crops resistant to abiotic stresses has been more limited, largely because few crops have close relatives with genes for resistance to these stresses.

Therefore biotechnology is being increasingly used to develop crops that can tolerate difficult growing conditions. Researchers have identified many genes involved in cold, heat and drought tolerances found naturally in some plants and bacteria and are trying to incorporate them in crops.

Plant Based Pharmaceuticals

Therapeutic drugs to treat cancer, infectious diseases, auto-immune diseases, cardiovascular diseases can potentially be grown in plants. Plant transgenic technology is being used to produce a plant that will generate a seed that expresses a desired therapeutic protein. This seed can propagate under the right growing conditions to yield plants and seed stock for producing the desired protein. The desired protein can be extracted from the seed to make a biopharmaceutical. Plant based therapeutics are expected to be much more cost effective.

1.7 World wide adoption and economic impact

Products arising from modern biotechnology such as genetically modified (GM) or transgenic crops are providing new opportunities to achieve sustainable productivity gains in agriculture.

The transgenic crops were grown worldwide in about 68 million hectares in 2003. The engineered traits include insect pest resistance, herbicide tolerance and virus resistance. The first, and as yet the only, GM crop permitted for commercial cultivation in India is the 'Bt cotton', conferring resistance to a lepidopteron insect pest, the bollworm. Transgenic crop (Bt Cotton) acreage in India is currently about 100,000 hectares. Following its commercial introduction in 2002, the Bt-cotton has found overwhelming support from farmers to the extent that almost all the domestic and multinational seed companies in the country are transferring the Bt transgene (and its variants) into their agronomically superior hybrids. In addition, transgenic research and development in a number of other crop plants for various agronomic and quality traits is being pursued by several public sector institutions, in India.

1.8 GM crops and public policy

There is a need for a reasoned and rational consideration of the benefits of GM crops and also of the rights of consumers to know what is in their food supply. Governments also need to frame suitable and transparent policy framework for bringing out comprehensive legislation on the industry and suitable safeguards to avoid the possible pitfalls. Governments around the world are hard at work to establish a regulatory process to monitor the effects of and approve new varieties of GM plants. Yet depending on the political, social and economic climate within a region or country, different governments are responding in different ways. For example, in Japan, the Ministry of Health and Welfare has announced that health testing of GM foods will be mandatory.

Ministry of Environment & Forests, Government of India notified the rules and procedures for the manufacture, import, use, research and release of GMOs as well as products made by the use of such organisms on December 5, 1989 under the Environment (Protection) Act, 1986 (EPA). These rules and regulations, commonly referred as Rules 1989, cover areas of research as well as large scale applications of GMOs and its products. These Rules are implemented by the Ministry of Environment & Forests and the Department of Biotechnology, Government of India.

1.9 Corporate control

GM crops have the potential to contribute to resolving food security and poverty issues in developing countries. However, the crops and traits developed so far have been targeted at the needs of large-scale commercial farmers, particularly in North America. More than three fourth of the total patents in the area of GM crops are being held by a single corporate, Monsanto.

1.10 GM crops and food security

Global cultivation of GM crops increased by 20 per cent in the year 2004. For the first time, the growth in GM crop areas was higher in developing countries than in developed ones.

i. Increasing crop resistance to insects and diseases and reducing weeds could help reduce crop losses and reduce dependence on costly fertilizers and herbicides, resulting in valuable savings for poor-resource farmers.

ii. Due to GM licensing agreements and production systems, farmers are pushed to monoculture and thus reduce the variety of crops planted for house hold consumption.

iii. After 2002, GM crops have been increasingly offered as food aid. Different countries of the African sub-continent have different approach to food aid in form of GM food. Examples of approaches to GM foods and food aid in Africa include:

   - ANGOLA - Banned imports of all GMO produce, except for food aid provided it was milled. The additional cost of milling discouraged some food donors.
   - SWAZILAND - Has no restrictions on GMO imports.
   - ZAMBIA - Banned import of all GMOs, citing concerns over environmental impact and effect on human health. Biosafety: issues and concerns

1.11 Safe or unsafe: a divide

While theoretical discussions have covered a broad range of aspects, the three main issues debated are tendencies to provoke allergic reaction (allergenicity), gene transfer and out-crossing to generate super weeds. Different GM crops include different genes inserted in different ways. This means that individual GM foods and their safety should be assessed on a case-by-case basis and that it is not possible to make general statements on the safety of all GM foods.

Feasibility and methods for post-marketing monitoring of GM food products, for the continued surveillance of the safety of GM food products, are still under discussion and development.

Environmental risk assessments

Environmental risk assessments cover both the GM crop concerned and the potential receiving environment. The assessment process includes evaluation of the characteristics of the GM crop and its effect and stability in the environment, combined with ecological characteristics of the environment in which the introduction will take place. The assessment also includes unintended effects which could result from the insertion of the new gene.

1.12 Ethics

GMO and ethics issues centre among other things on patenting, cloning of life forms and biopiracy. In Africa, many communities and consumers express ethical concerns about "playing god" as plants are transformed in unnatural ways and the implications for traditional beliefs and values.

i. Patenting genetic material traditionally available to a community without allowing the community free use of the material or providing any return to the community affects the fair and equitable distribution of resources, a necessity in the development of a sustainable society. There is concern that the access and intellectual property issues related to "terminator gene" technologies will lead to increasing dependence on industrialized nations by African countries and domination of world food production by a few multinational companies.

ii. Biopiracy is also of growing concern particularly as many African countries lack the legislative and enforcement systems to control illegal extraction of genetic resources. Additionally, the benefit sharing systems for the use of these assets and of traditional knowledge are poorly developed.

1.13 Methodology

The report has been compiled based largely on desk research and analysis. A detailed literature review has been undertaken to identify relevant data. Primary data for impacts of commercial cultivation were, of course, not available for every crop, in every year and for each country, but all representative, previous research has been utilised. The findings of this study have been used as the basis for the analysis presented.

1.14 Objectives

The advent of the genetically modified seeds and plant for increasing productivity and reducing crop losses is a boon for countries like India from the point of view of food security and fighting hunger and poverty. The safety concerns associated with use of GMOs and products there of broadly fall under three categories: risk to human health, environmental concerns and social and ethical grounds. Keeping this in view following objectives are formulated for the present study:

1. **GM crops : a necessity or research apprehension.**
2. **Divide between the developing and developed world in use of this biological invention.**
3. **How it addresses food security and biosafety?**

1.15 Scheme of Chapterization

The given study on the GM crops will be chapterized in the following form:

I. Introduction

II. Review of Literature

III. Methodology

IV. Analysis and Major Conclusion Drawn

V. Recommendations and Prospects & Priorities for Future Studies

2. Review of Literature

India has been practicing conventional biotechnology for several decades whereas modern biotechnology involving Genetically Modified Organisms (GMOs) is relatively new. The use of biotechnology products and processes in diverse application areas has great promises for the sectors of agriculture, medicine and other industrial applications. There are, however, concerns about the potential risks associated with their use for human health, environment and biological diversity.

2.1 GM Crops a Research Perspective

During 1970-90 the Green Revolution brought about greatly improved crop yields in many, but by no means all, parts of the developing world. Poverty and hunger fell dramatically. However, Africa and parts of Asia saw little gain, and the initial rate of improvement of the Green Revolution was not sustained during 1985-90. The best areas had already been saturated with semi-dwarf wheat and rice. Further yield increases were held back by water shortages, soil problems, and the emergence of new types of pest and disease.

To overcome these problems the concept of GM crops emerged. GM crops are a relatively young field of research. The first GM crops were not planted commercially until the mid-1990s. New Leaf Potato, marketed by Monsanto, was the first such crop approved for human consumption in the United States, in 1995. This potato produces a protein toxic to the Colorado potato beetle and significantly reduces crop loss while saving on the use of pesticides. However, the sale of seeds for this crop was discontinued in 2001, after sales failed to capture more than 5% of the potato seed market, due to its social unacceptance. The timeline from inception of this concept is shown in Table 2.

Since the introduction of first transgenic crop for commercial use in 1995 in USA i.e. the Flavr Savr tomatoes with delayed ripening, extensive research and development efforts were initiated all over the world. The areas of crop improvement currently being targeted using transgenic techniques include resistance to a variety of pests, pathogens and weed control agents, improvement in nutritional content and improved survival during environmental stress. Research is also carried out into production of new and improved raw materials for a wide range of products including Medicines.

Approval for commercial planting and use of transgenic crops follows many years of research involving laboratory and field-testing, peer review and government regulatory procedures. Nineteen crops have so far been approved in various countries for planting in various countries across the world incorporating one or more of the basic phenotypic characteristics such as fatty acid composition, fertility restoration, herbicide tolerance, insect resistance, male sterility, modified color, mutations, reduced nicotine, delayed ripening and virus resistance.

List of these products along with the genetically improved trait and countries where they have been approved is given in the Table-3.

Table – 2

GM crop development timeline.

1950	– First regeneration of entire plants from an in-vitro culture.
1973	– The ability to isolate specific genes is created.
1980s	– Protocols to transfer piece of DNA from one organism to another developed.
1983	– A tobacco plant resistant to an anti-biotic is the first transgenic plant.
1985	– Engineered plants resistant to bacteria, viruses, and insects are field tested for the first time.
1990	– The first successful field trial of GM herbicide tolerant cotton is conducted in the USA. – Engineered cotton (Bt) is field tested successfully. – DEKALB receives a patent for engineered corn.
1994	– The first genetically engineered food product, the FlavrSavr® tomato, receives US Food and Drug Administration approval.
1995	– GM technology arrived in India in 1995, when the US biotech giant Monsanto teamed up with India's MAHYCO to import Bt cotton seeds – Australian Genetic Manipulation Advisory Committee (GMAC) allows unrestricted, commercial release of a GM blue carnation in Australia.
1996	– Ingard® insect resistant (Bt) cotton is grown commercially in Australia.
1998	– 40 million hectares of GM crops are planted globally, predominantly soy, cotton, canola and corn.
1999	– In response to the exponential growth in discoveries and applications for the use of gene technology, Australia conducts its first ever Consensus Conference on gene technology in the food chain.
2000	– Arabidopsis thaliana becomes the first entire plant genome to be sequenced. 'Golden rice', a genetically modified variety with genes added which produce a vitamin A precursor, is created.
2001	– A single gene from Arabidopsis is inserted into tomato plants to create the first crop able to grow in salty water and soil.
2002	– India allowed farmers to cultivate Bt cotton – the only GM crop commercially grown in India to date. – Researchers sequence the DNA of rice, the main food source for two-thirds of the world's population. It is the first crop plant to have its genome decoded.
2003	– Office of the Gene Technology Regulator approves commercial release of herbicide tolerant GM canola crops.

	– UK approves its first commercial biotech crop in eight years, a GM herbicide-resistant corn used for cattle feed. – US Environmental Protection Agency approves the first transgenic rootworm-resistant corn. – Japanese researchers develop a biotech coffee bean that is naturally decaffeinated.
2004	– In Australia, despite regulatory approval for GM canola, most state governments place moratoria on growing GM canola in response to consumer concerns. – GM maize is approved for planting in Britain.
2006	– Supreme court bans GM field trails in India. – German biotech firm BASF gets permission to plant blight-resistant GM potatoes at two trial sites in Britain.
	– Supreme court allows contained GM field trials in India – Government backs call from industry and farmers to bring GM to Britain.
2008 and beyond	– Within the next twenty years a second generation of GM crops is expected with properties that have more direct consumer benefit such as elimination of allergens in food, increased nutritional content, and lower fat and oil levels. – Third generation GM crops may have properties like salt tolerance, drought resistance, drugs and vaccines within them, and plastic starter chemicals

Table-3

Transgenic crops approved for commercial use (globally).

S.No.	Crop	Trait	Countries
1.	Alfalfa	Herbicide tolerance	USA, Canada, Mexico
2.	Argentine Canola	Herbicide tolerance and improved protection against weeds	Canada, USA, Japan, Australia
3.	Carnation	Increased shelf life by delayed ripening, modified flower colour and Herbicide tolerance	Australia, European Union
4.	Chicory	Herbicide tolerance, improved protection against weeds and higher Yields	European Union
5.	Cotton	Improved insect protection, herbicide tolerance and improved protection against weeds	Japan, Australia, USA, China, Mexico, South Africa, Argentina, India, Indonesia, Philippines, Brasil
6.	Flax Linseed	Herbicide tolerance antibiotic resistance and improved weed protection	Canada
7.	Green pepper	Virus resistance	China
8.	Maize	Herbicide tolerance, improved against weed Protection, resistance insects and restored fertility of seeds	Canada, Japan, USA, Argentina, European Union, South Africa, Philippines, Switzerland, Taiwan, China, U.K., Korea, Russia, Uruguay
9.	Melon	Delayed ripening	USA

S.No.	Crop	Trait	Countries
10.	Papaya	Papaya Virus Resistance	Canada, USA
11.	Polish Canola	Herbicide tolerance and improved weed control	Canada
12.	Potato	Improved protection from insect and leaf roll virus	Australia, Canada, Japan, Philippines, USA
13.	Rice	Herbicide resistance	USA
14.	Soybean	Improved weed control and herbicide tolerance, increased cooking quality	USA, Argentina, Japan, Canada, Argentina, Uruguay, Mexico, Brazil and South Africa, Czech Republic, European Union, Korea, Russia, Switzerland, Taiwan, U.K., Philippines and Australia
15.	Squash	Resistance against watermelon mosaic virus and zucchini yellow mosaic virus	Canada, USA
16.	Sugar beet	Herbicide tolerance	Canada, Japan, USA, Philippines, Australia
17.	Sunflower	Herbicide tolerance	Canada
18.	Tobacco	Herbicide tolerance	Herbicide tolerance USA
19.	Tomato	Improved shelf life, taste, color and texture, improved insect resistance, virus resistance	USA, Mexico, Japan, China, Canada

Source: http://www.agbios.com/

Status in India

In view of the importance and potential of transgenic crops, extensive efforts have been initiated in India for development of transgenic crops. As of now, Bt cotton containing the Cry1Ac gene from is the only transgenic crop approved for commercial cultivation in India. The approval was first accorded to M/s Maharashtra Hybrid Seeds Company Ltd. (MAHYCO) in 2002. Subsequently, several other companies have taken sub-licenses from MAHYCO and in 2005, 20 hybrids of Bt cotton were approved for commercial cultivation in nine states in the country.

Extensive efforts have been initiated under the aegis of the Department of Biotechnology (DBT) for promoting research and development in this area. DBT supported the establishment of **Centres for Plant Molecular Biology (CPMB)** as early as in **1990**. A total of six such centers were set up initially at various universities/institutions namely Jawaharlal Nehru University (New Delhi), Madurai Kamaraj University (Madurai), Tamil Nadu Agricultural University (Coimbatore), Osmania University (Hyderabad), National Botanical Research Institute (Lucknow) and Bose Institute (Kolkata). A seventh center was established at the University of Delhi South Campus in 1997. DBT has supported over the last 12 years a large number of research projects which deal with the development of in-vitro regeneration and genetic transformation protocols of important crops species grown in India and the development of transgenics with genes of agronomic importance. To further strengthen research in the area of crop biotechnology, a new institute

National Centre for Plant Genome Research (NCPGR) has been established in New Delhi with a mandate to strengthen plant biotechnology research in India.

There are more than 20 crops under research in India as listed below:

i. Bhendi, ii. Black gram, iii. Green gram, iv. Brassica (Mustard), v. Brinjal, vi. Cabbage, vii. Cauliflower, viii. Chickpea, ix. Cotton, x. Groundnut, xi. Muskmelon, xii. Rapeseeds, xiii. Pigeonpea, xiv. Potato, xv. Rice, xvi. Sorghum, xvii. Sugarcane, xviii. Sunflower, xix. Tobacco, xx. Tomato, xxi. Watermelon, xxii. Wheat,

The important traits being targeted for development of transgenics include insect resistance, herbicide tolerant, viral and fungal disease resistance and stress tolerance. More than 50 institutions in public and private sector are engaged in transgenic crops and development. These include 34 research institutions and 20 private companies. Thirteen crops have been approved for conducting contained limited field trials in India s given in Table-4. The trials are being conducted by both public and private sector institutions.

2.2 GM crops global status and acceptance

Probably no discovery in plant sciences has had, in so short a time, such far reaching consequences on agriculture as the method reported in 1983 for the genetic modification of plants using gene technology.

Table-4

Transgenic crops approved for conducting contained limited field trials (including multi-location field trials).

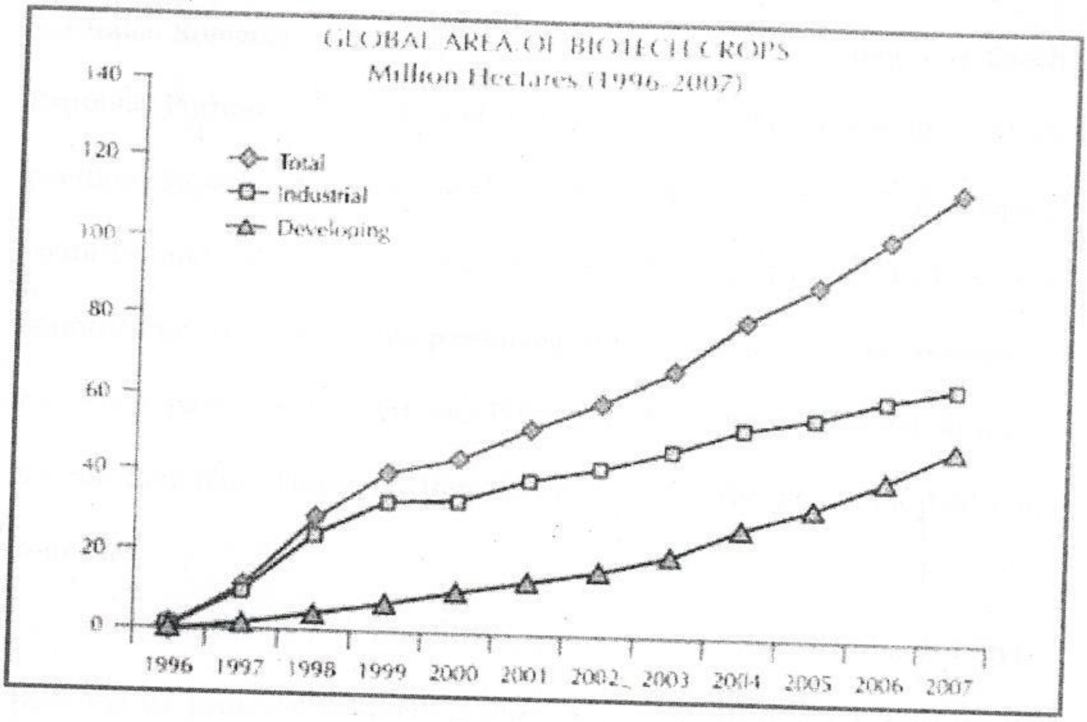
S. No.	Crop	Organization	Transgene
1.	Brinjal	MAHYCO, Mumbai Sungro Seeds Ltd, New Delhi IARI, New Delhi	cry1Ac cry1Ac cry1F
2.	Cabbage	Sungro Seeds Ltd, New Delhi	cry1 Ac
3.	Cauliflower	Sungro Seeds Ltd, New Delhi	cry1 Ac
4.	Corn	Monsanto, Mumbai Metahelix Life Sciences, Bangalore	cry1Ab Modified Mu-element (Turbo-Mu)
5.	Groundnut	ICRISAT, Hyderabad	Coat protein of IPCV
6.	Mustard	UDSC, New Delhi	barnase & barstar
7.	Okra	MAHYCO, Mumbai	cry1Ac
8.	Pigeonpea	ICRISAT, Hyderabad	cry1Ac
9.	Rice	IARI, New Delhi MAHYCO, Mumbai Metahelix Life Sciences, Bangalore	cry1Ac, cry1Aa + cry1B cry1 Ac NHX gene
10.	Tomato	IARI, New Delhi MAHYCO, Mumbai	antisense replicase gene of tomato leaf curl virus cry1Ac

Source: Department of Biotechnology, Government of India

Over the last eleven years, 1996 to 2006, farmers have consistently increased their plantings of biotech crops by double-digit growth rates every single year since biotech crops were first commercialized in 1996. Remarkably, the global biotech crop area increased more than sixty-fold in the first eleven years of commercialization, making biotech crops the fastest adopted crop technology in recent history. The global area of approved biotech crops in 2006 was 102 million hectares, up from 90 million hectares in 2005. In 2007, for the twelfth consecutive year, the global area of biotech crops continued to soar. Remarkably, growth continued at a sustained double-digit growth rate of 12%, or 12.3 million hectares (30 million acres) - the second highest increase in global biotech crop area in the last five years - reaching 114.3 million hectares (Fig.-1). It is noteworthy that more than half (55% or 3.6 billion people) of the global population of 6.5 billion live in the 22 countries where biotech crops were grown in 2006 and generated significant and multiple benefits. Also more than half (52% or 776 million hectares of the 1.5 billion hectares of arable land) of the cropland in the world is in the 22 countries where approved biotech crops were grown in 2006. A historic milestone was reached in 2006 when the accumulated area of biotech crops planted in the last eleven years, 1996 to 2006, exceeded 500 million hectares (577 million hectares) for the first time.

Figure - 1

Global Area of Biotech Crops.



An increase of 12%, 12.3 Mha between 2006-07

Source: James, C. 2007

In 2006, 22 countries grew biotech crops, 11 developing countries and 11 industrial countries; they were, in order of cropping area, USA, Argentina, Brazil, Canada, India, China, Paraguay, South Africa, Uruguay, Philippines, Australia, Romania, Mexico, Spain, Colombia, France, Iran, Honduras, Czech Republic, Portugal, Germany, and Slovakia. In 2007, the number of countries planting biotech crops increased to 23, and comprised 12 developing countries and 11 industrial countries (Table-5). The two new biotech crop countries in 2007 were Chile producing over 25,000 hectares of commercial biotech crops for seed export, and Poland, an EU country, growing Bt maize for the first time. However, Iran dropped out of the list of the GM crop countries.

In 2006, the US followed by Argentina, Brazil, Canada, India and China were the six principal adopters of biotech crops globally, with India for the first time replacing China at number five in world ranking by planting more Bt cotton than China. In 2007, the USA, followed by Argentina, Brazil, Canada, India and China continued to be the principal adopters of biotech crops globally, with the USA retaining its top world ranking with 57.7 million hectares (50% of global biotech area)

The largest absolute increase in biotech crop area in any country in 2006 was in the US at 4.8 million hectares, followed by India 2.5 million hectares, Brazil 2.1 million hectares, with Argentina and South Africa with 0.9 million hectares each. India had the largest year-on-year proportional increase, with almost a three-fold or 192 % increase from 1.3 million hectares in 2005 to 3.8 million hectares in 2006, followed by South Africa at 180% from 0.5 million hectares in 2005 to 1.4 million hectares in 2006, and the Philippines with over a 100% increase from approximately 0.1 million hectares in 2005 to 0.2 million hectares in 2006. 10.3 million farmers from 22 countries planted biotech crops in 2006, up from 8.5 million farmers in 2005. Of the 10.3 million, 90% or 9.3 million (up significantly from 7.7 million in 2005) were small, resource-poor farmers from developing countries whose increased income from biotech crops contributed to their poverty alleviation. Of the 9.3 million small farmers, most of whom were Bt cotton farmers, 6.8 million were in China, 2.3 million in India, 100,000 in the Philippines, several thousand in South Africa, with the balance in the other seven developing countries which grew biotech crops in 2006. This initial modest contribution of biotech crops to the Millennium Development Goal of reducing poverty by 50% by 2015 is an important development, which has enormous potential in the second decade of commercialization from 2006 to 2015.

Biotech soybean continued to be the principal biotech crop in 2006, occupying 58.6 million hectares (57% of global biotech area), followed by maize (25.2 million hectares at 25%), cotton (13.4 million hectares at 13%) and canola (4.8 million hectares at 5% of global biotech crop area).

From the genesis of commercialization in 1996, to 2006, herbicide tolerance has consistently been the dominant trait followed by insect resistance and stacked genes for the two traits. In 2006, herbicide tolerance, deployed in soybean, maize, canola, cotton and alfalfa occupied 68% or 69.9

million hectares of the global biotech 102 million hectares, with 19.0 million hectares (19%) planted to Bt crops and 13.1 million hectares (13%) to the stacked traits of Bt and herbicide tolerance. The stacked product was the fastest growing trait group between 2005 and 2006 at 30% growth, compared with 17% for insect resistance and 10% for herbicide tolerance.

It is noteworthy that more than half (55% or 3.6 billion people) of the global population of 6.5 billion live in the 22 countries where biotech crops were grown in 2006 and generated significant and multiple benefits. Biotech crops achieved a very important milestone in 2007 with humanitarian implications – the number of small and resource-poor farmers benefiting from biotech crops in developing countries exceeded 10 million for the first time. Of the global total of 12 million beneficiary biotech farmers in 2007, (up from 10.3 million in 2006), over 90% or 11 million (up significantly from 9.3 million in 2006) were small and resource-poor farmers from developing countries

This initial, although small contribution of increased small farmer income from biotech crops towards the Millennium Development Goals of reducing poverty by 50% by 2015 is a very encouraging and important development.

While 23 countries planted commercialized biotech crops in 2007, an additional 29 countries, totaling 52, have granted regulatory approvals for biotech crops for import for food and feed use and for release into the environment since 1996. A total of 615 approvals have been granted for 124 events for 23 crops. Thus, biotech crops are accepted for import for food and feed use and for release into the environment in 29 countries, including major food importing countries like Japan, which do not plant biotech crops. Of the 52 countries that have granted approvals for biotech crops, Japan tops the list followed by USA, Canada, South Korea, Australia, Mexico, the Philippines, New Zealand, the European Union and China. Maize has the most events approved (40) followed by cotton (18), canola (15), and soybean (8). The event that has received regulatory approval in most countries is herbicide tolerant soybean with 24 approvals, followed by insect resistant maize and herbicide tolerant maize both with 18 approvals, and insect resistant cotton with 16 approvals worldwide.

The most important constraint to biotech crops in most developing countries, that deserves highlighting, is the lack of appropriate cost-effective and responsible regulation systems that incorporate all the lessons of a dozen years of regulation. Current regulatory systems in most developing countries are usually unnecessarily cumbersome and in many cases it is impossible to implement the system to approve products.

2.3 Indian Status

India is highly dependent on agriculture which generates almost one quarter of its GDP and provides two thirds of its people with their means of survival. India is a nation of small resource-poor farmers, most of whom do not make enough income to cover their meager basic needs and expenditures.

Table- 5.

Global Area of Biotech Crops in 2007: by Country (Million hectares).

Rank	Country	Area	Biotech Crops
1*	USA*	57.7	Soybean, maize, cotton, canola, squash, papaya, alfalfa
2*	Argentina*	19.1	Soybean, maize, cotton
3*	Brazil*	15.0	Soybean, cotton
4*	Canada*	7.0	Canola, maize, soybean
5*	India*	6.2	Cotton
6*	China*	3.8	Cotton, tomato, poplar, petunia, papaya, sweet pepper
7*	Paraguay*	2.6	Soybean
8*	South Africa*	1.8	Maize, soybean, cotton
9*	Uruguay*	0.5	Soybean, maize
10*	Philippines*	0.3	Maize
11*	Australia*	0.1	Cotton
12*	Spain*	0.1	Maize
13*	Mexico*	0.1	Cotton, soybean
14	Colombia	<0.1	Cotton, carnation
15	Chile	<0.1	Maize, soybean, canola
16	France	<0.1	Maize
17	Honduras	<0.1	Maize
18	Czech Republic	<0.1	Maize
19	Portugal	<0.1	Maize
20	Germany	<0.1	Maize
21	Slovakia	<0.1	Maize
22	Romania	<0.1	Maize
23	Poland	<0.1	Maize

* 13 biotech mega-countries growing 50,000 hectares, or more, of biotech crops

Source: Clive James, 2007.

The National Sample Survey last conducted in 2003, reported that 60.4% of rural households were engaged in farming indicating that there are 89.4 million farmer households in India. Sixty percent of the farming households own less than 1 hectare of land, and only 5% own more than 4 hectares. Only the 5 million farming households (5% of 90 million) have an income that is greater than their expenditures. The average income of farm households in India (based on 45 Rupees per US Dollar) was $46 per month and the average consumption expenditures was $62. Thus, of the 90 million farmer households in India, approximately 85 million, which represent about 95% of all farmers, are small resource-poor farmers who do not make enough money from the land to make ends meet - in the past, these included the vast majority of the 5 million or more Indian cotton farmers. India has a larger area of cotton than any country in the world - 9 million hectares cultivated by approximately 5 to 5.5 million farmers. Whereas India's cotton area represents 25% of the global area of cotton, in the past it produced only 12% of world production because Indian cotton yields were some of the lowest in the world.

Bt cotton, which confers resistance to important insect pests of cotton, was first adopted in India as hybrids in 2002. India grew approximately 50,000 hectares of officially approved Bt cotton hybrids for the first time in 2002, and doubled its Bt cotton area to approximately 100,000 hectares in 2003. The Bt cotton area increased again four-fold in 2004 to reach over half a million hectares. In 2005, the area planted to Bt cotton in India continued to climb reaching 1.3 million hectares, an increase of 160% over 2004.

In 2006, the record increases in adoption in India continued with almost a tripling of area of Bt cotton from 1.3 million hectares to 3.8 million hectares. In 2006, this tripling in area was the highest year-on-year growth for any country in the world. Of the 6.3 million hectares of hybrid cotton in India in 2006, which represents 70% of all the cotton area in India, 60% or 3.8 million hectares was Bt cotton - a remarkably high proportion in a fairly short period of five years.

According to statistics released by the Cotton Association of India in 2008, transgenic Bt cotton represents 66 per cent of Indian cotton grown in the current season. Cotton acreage in India totals more than 9.5 million hectares. A record harvest of 31 million bales is expected this season, due in part to the bollworm resistance and high yield of Bt cotton.

The distribution of Bt cotton in the major growing states in 2004, 2005 and 2006 is shown in Table-6. The major states growing Bt cotton in 2006, listed in order of hectarage, are Maharashtra (1.840 million hectares representing almost half, 48% of all Bt cotton in India in 2006) followed by Andhra Pradesh (830,000 hectares or 22%), Gujarat (470,000 hectares or 12%), Madhya Pradesh (310,000 hectares or 8%), and 215,000 hectares (6%) in the Northern Zone and the balance in Karnataka and Tamil Nadu and other states.

Table-6

Adoption of Bt Cotton in India, by Major States, in 2004, 2005, and 2006 ('000 hectares).

State	2004	2005	2006
Maharashtra	200	607	1,840
Andhra Pradesh	75	280	830
Gujarat	122	150	470
Madhya Pradesh	80	146	310
Northern Zone*	- -	60	215
Karnataka	18	30	85
Tamil Nadu	5	27	45
Other	- -	- -	5
Total	**500**	**1,300**	**3,800**

* Punjab, Haryana, Rajasthan

Source: Brooks & Barfoot, 2006.

2.4 Economic impact

In 2007, the global market value of biotech crops, estimated by Cropnosis, (http://www.cropnosis.com) was US$6.9 billion representing 16% of the US$42.2 billion global crop protection market in 2007, and 20% of the ~US$34 billion 2007 global commercial seed market.

It is estimated that in India, approximately 2.3 million small farmers planted on average 1.65 hectares of Bt cotton in 2006. The number of farmers growing Bt cotton hybrids in India has increased from 300,000 small farmers in 2004 to 1 million in 2005, with over a two-fold increase in 2006 to 2.3 million farmers, who are reaping significant benefits from the technology. Coincidental with the steep increased adoption of Bt cotton between 2002 and 2005, the average yield of cotton in India, which had one of the lowest yields in the world, increased from 308 kg per hectare in 2001-02 to 450 kg per hectare in 2005-2006, with most of the increase in yield of up to 50% or more attributed to Bt cotton.

The work of Bennett et al. (2004) confirmed that the principal gain from Bt cotton in India is the significant yield gains estimated at 45% in 2002, and 63% in 2001, for an average of 54% over the two years. Taking into account the decrease in application of insecticides for bollworm control, which translates into a saving, on average, of 2.5 sprays, and the higher cost of Bt cotton seed, Brookes and Barfoot (2005) estimated that the net economic benefits for Bt cotton farmers in India were $139 per hectare in 2002, $324 per hectare in 2003, $171 per hectare in 2004, and $260 per hectare in 2005, for a four year average of approximately $225 per hectare. The benefits at the farmer level translated to a national gain of $339 million in 2005 and accumulatively $463 million for the period 2002 to 2005. Other studies report results in the same range, acknowledging that benefits will vary from year to year due to varying levels of bollworm infestations. A recent study by Gandhi and Namboodiri (2006) reported a yield gain of 31%, a significant reduction in the number of pesticide sprays by 39%, and an 88% increase in profit or an increase of $250 per hectare for the 2004 cotton growing season.

2.4 GM crops: benefits and controversies

Benefits

Crop improvement:

- Enhanced taste and quality
- Reduced maturation time
- Increased nutrients, yields, and stress tolerance
- Improved resistance to disease, pests, and herbicides
- New products and growing techniques

Environment

- "Friendly" bio-herbicides and bio-insecticides
- Conservation of soil, water, and energy
- Bio-processing for forestry products
- Better natural waste management
- More efficient processing

Society

- Increased food security for growing populations

Controversies

Safety

- Potential human health impact: allergens, transfer of antibiotic resistance markers, unknown effects Potential environmental impact: 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 Industrialised nations by developing countries
- Biopiracy – 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 confounds labeling attempts

Society

- New advances may be skewed to interests of rich countries

2.5 Future Prospects

Genetically modified crop technology has revolutionized agriculture in the United States, Canada, China, Argentina Brazil and India. It exhibits the potential to have much wider impact, solving many of the current problems in agriculture worldwide. The types of GM crops that may become available in the future could boost crop yields while enhancing the nutritional value of staple foods and eliminating the need for inputs that could be harmful to the environment. 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, without evidence of adverse health or environmental impacts. Yet, in other than the six countries mentioned above, the GM crop movement has had little or no impact. In those parts of the developing world where an agricultural revolution might be most welcome, the GM crops are yet to be embraced.

The GM crop movement shows great promise. Like the green revolution before it, the GM crop movement has the potential to achieve substantial production increases in regions of need and to reduce the need for agricultural chemicals and scarce resources, such as water. Both the successes and failures of the green revolution provide useful lessons for how to make

GM crop technology a desirable and sustainable agricultural movement in the developing world.

The success of green revolution demonstrates that, to create GM crops truly beneficial to the developing world, plant breeders and other scientists must be familiar with the local environment and the planting methods of the region for which they are developing crops. Often, at times, agricultural conditions in developing regions are so different from those in the industrial world that it is difficult for industrial-world scientists to know how to devise appropriate technologies for those regions. During the Green Revolution, plant scientists traveled abroad extensively, developing crop seeds that were best suited to particular regions given their particular weather conditions, plant pests, water availability, and planting seasons. Importantly, these plant scientists trained others in each region to be able to carry out the green revolution practices independently.

3. Methodology

The present study is formulated in order to understand the various issues related to GM crops, their necessity in different parts of the world and their importance in the developing world. It is also proposed to study their role in human health and industrial development along with their contribution to food security and concerns related to biosafety.

The dissertation report has been compiled based largely on desk research and analysis. A detailed literature review has been undertaken to identify relevant data. Primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, but representative, previous research data has been utilised.

Collection of data, policies and decisions globally comprised of:

I. Study of research efforts and their aim in developing GM crops.

II. Impact on economic growth and poverty elevation.

III. Impact on environment.

IV. Nutritional food security.

V. Corporate Control.

VI. Ethical issues and Intellectual Property Rights.

The data collected from different sources like research papers, review articles and internet has been recorded and used in systematic manner to arrive at meaningful conclusions. The processing of data in terms of area under cultivation of GM crops world wide and its socio economic impact in terms of produce, income and impact on environment has been focused.

Social aspects like nutritional value enhancement and ethical issues have been discussed based on adoption and acceptance rate of these crops in developing countries.

The analysis presented is largely based on the average performance and impact recorded in different crops. The economic performance and environmental footprint of the technology at the farm level does vary widely, both between and within regions and countries. As a result, the impact of this technology, and any new technology, GM or otherwise, is subject to variation at the local level. Therefore, the performance and impact should be considered on a case-by-case basis in terms of crop and trait combinations.

In order to study the progress of GM crops from development to commercialization, data were collected by regulatory stage, emphasizing the most advanced events possible. Four stages were used: experimental (transformation events that produce stable transgenic plants derived from multiple generations at the laboratory/greenhouse/glasshouse scale); confined field trials (transformation events expressing stable traits in small-scale, single or multi-location confined trials); scale-up (transgenic plants advancing into larger, pre-commercial trials); or commercial release (products marketed to farmers through privately or publicly owned seed companies or other institutional mechanisms).

Agricultural production systems are dynamic and vary with time. This analysis seeks to address this issue, wherever possible, by comparing GM production systems with the most likely conventional alternative that could provide competitive levels of efficacy if GM technology had not been available. This approach has been used by other researchers as well.

4. Analysis and Major Conclusion Drawn

The world's population is expected to almost double by the year 2050, making food security the most important social issue for the next 30 years. Food production will have to be doubled or preferably tripled to meet the needs of the expected 6 billion people, 90% of whom will reside in the developing world.

This study presents the findings of research into the issues and impact of genetically modified (GM) crops in ensuring food security since their commercial introduction in 1996. Several studies have investigated the economic and environmental perspectives of GM crops, but these have usually been limited by trait, country, and/or year. The economic impact analysis concentrates on farm income effects, because this is a primary driver of adoption amongst farmers and is very important from the Indian agriculture perspective also. The environmental impact analysis focuses on changes in the use of insecticides and herbicides with GM crops and the resulting impact on the environmental load from crop production. The contribution of GM crops towards reducing global greenhouse gas (GHG) emissions because of the importance of this issue to the global environment has also been analysed.

4.1 Adoption of GM crops

GM varieties of soybeans, corn, and cotton have been available commercially since 1996 (Table-2, Table-3). Farmers have adopted herbicide-tolerant (HT) varieties, which help control weeds, faster than insect-resistant varieties. Weeds are such a pervasive pest for soybeans, corn, and cotton that over 90 percent of planted acreage for each crop was treated with herbicides in recent years. Acreage share for HT soybeans has expanded more rapidly than that for HT varieties of cotton and corn (refer para 2.2).

4.2 *Impact on Farm Income*

GM technology has had a very positive impact on farm income derived from a combination of enhanced productivity and efficiency gains. In 2004, the direct global farm income benefit from GM crops was $4.8 billion. If the additional income arising from second crop soybeans in Argentina is considered, this income gain rises to $6.5 billion. This is equivalent to adding between 3.1% and 4.2% to the value of global production of the four main crops of soybeans, maize, canola, and cotton—a substantial impact. Since 1996, farm incomes have increased by over $19 billion or $27 billion inclusive of second-crop soybean gains in Argentina (Table - 7).

The largest gains in farm income have arisen in the soybean sector, largely from cost savings, where the $4.14 billion additional income generated by GM (Herbicide Tolerance) soybeans in 2004 has been equivalent to adding 9.5% to the value of the crop in the GM-growing countries, or adding the equivalent of 6.7% to the $62 billion value of the global soybean crop (Brookes & Barfoot, 2005). Substantial gains have also arisen in the cotton sector through a combination of higher yields and lower costs.

Table - 7

Global farm income benefits from growing GM crops, 1996-2004 (US$ million).

Trait	2004 increase in farm income	1996-2004 increase in farm income	2004 farm income benefit as % of total value of production of these crops in GM adopting countries	2004 farm income benefit as % of total value of global production of these crops
GM HT soybeans	2,440	9,300	5.6	4.0
GM HT maize	152	579	0.6	Less than 0.5
GM HT cotton	145	750	1.4	0.53
GM HT canola	135	713	8.3	1.34
GM IR maize	415	1,932	1.4	0.8
GM IR cotton	1,472	5,726	10.5	5.3
Others	20	37	N/a	N/a
Totals	4,779	19,037	5.3	3.1

HT = herbicide tolerant,
IR = insect resistant,
Others = Virus-resistant papaya and squash, rootworm-resistant maize.

Source: *http://www.agbioforum.org*

In 2004, cotton farm income levels in the GM-adopting countries increased by $1.62 billion, and since 1996, the sector has benefited from an additional $6.5 billion. The 2004 income gains are equivalent to adding nearly 12% to the value of the cotton crop in these countries, or 5.8% to the $28 billion value of total global cotton production (Table-8). This is a substantial increase in value added terms for two new cotton seed technologies.

Significant increases to farm incomes have also resulted in the maize and canola sectors. The combination of GM insect resistance (IR) and GM HT technology in maize has boosted farm incomes by over $2.5 billion since 1996 (Table-8). In the North American canola sector, an additional $713 million has been generated (Brookes & Barfoot, 2005).

Indian status

Transgenic Bt cotton represents 66 per cent of Indian cotton grown in the current season (CAI 2008). Cotton acreage in India totals more than 9.5 million hectares. A record harvest of 31 million bales is expected this season, due in part to the bollworm resistance and high yield of Bt cotton (Table-9).

The transgenic cotton is found most extensively in the central Indian zone, where it is grown on more than 4 million hectares. Areas of 1.08 million and 870,000 hectares respectively are cultivated in the southern and northern zones. In all of these major regions, Bt cotton occupies two-thirds to three-quarters of the total area for the crop.

Table - 8

GM crop farm income benefits, selected countries, 1996-2004 (US$ million).

	GM HT soybeans	GM HT maize	GM HT cotton	GM HT canola	GM IR maize	GM IR cotton	Total
United States	6,371	564	746	96	1,626	1,301	10,704
Argentina	9,965	n/a	n/a	n/a	120	16	10,101
Brazil	829	n/a	n/a	n/a	n/a	n/a	829
Paraguay	80	n/a	n/a	n/a	n/a	n/a	80
Canada	55	16	n/a	617	119	n/a	807
South Africa	0.8	0.2	0.01	n/a	44	11	56.01
China	n/a	n/a	n/a	n/a	n/a	4,160	4,160
India	n/a	n/a	n/a	n/a	n/a	124	124
Australia	n/a	n/a		n/a	n/a	70	70
Mexico	n/a	n/a	n/a	n/a	n/a	41	41

Note. Argentine GM HT soybeans includes $8,050 billion benefits from second-crop soybeans.

N/a = not applicable.

HT = herbicide tolerant,
IR = insect resistant,
Others = Virus-resistant papaya and squash, rootworm-resistant maize.

Source: *http://www.agbioforum.org*

Table-9

The State-wise details of area and production of Bt cotton.

State	Area		Production	
	06-07	07-08(E)	06-07	07-08(E)
Punjab	6.07	6.48	26.00	24.00
Haryana	5.30	4.78	16.00	16.00
Rajasthan	3.50	3.68	8.00	9.00
North Zone	14.87	14.94	50.00	49.00
Gujarat	23.90	25.16	101.00	110.00
Maharashtra	30.70	31.91	52.00	60.00
M.P.	6.39	6.62	18.00	21.00
Central Zone	60.99	63.69	171.00	191.00
A.P.	9.72	10.96	35.00	43.00
Karnataka	3.75	3.71	6.00	8.00
Tamil Nadu	1.22	1.23	5.00	5.00
South Zone	14.69	15.90	46.00	56.00
Others	0.87	0.77	1.00	2.00
Loose Cotton			+ 12.00	+ 12.00
All India	91.42	95.30	280.00	310.00

E=Estimated

Area in lakh ha.

Production in lakh bales of 170 kg each

Source: As estimated by the CAB (2008)

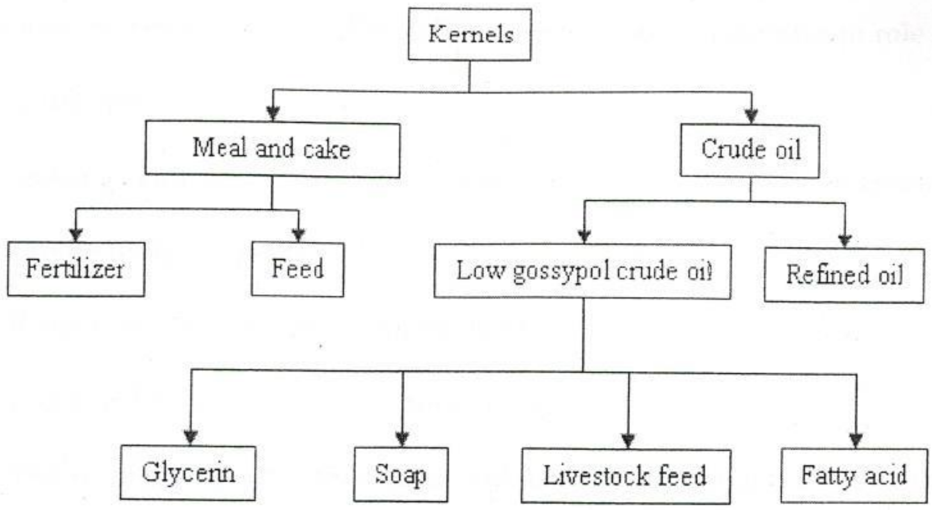
Despite extensive field areas, India produces an average of only 553 kg of cotton per cultivated hectare and lags thereby at a significant distance to other cotton-producing countries. Global averages are recorded as 765kg of cotton per cultivated hectare. However, the use of Bt cotton has fostered Indian yields since the season of 2000-01, in which India produced 338kg less cotton per hectare than the world average. For the current growing season of 2007-08, the national shortfall is anticipated to be only 212 kg per hectare and the four major cotton-producing states of Gujarat, Tamil Nadu, Andhra Pradesh and the Punjab are expected to achieve yields of 743, 691, 667 and 630 kilograms of cotton per hectare respectively.

Apart from the fibre, cottonseed is a good source of oil and other by-products (figure-2). Cottonseed oil is mechanically extracted from the cottonseed by means of screw or press. Cottonseed oil ranked fifth in production and consumption volume among vegetable oils over the period 1961-2003, accounting for approximately 8% of the world's vegetable oil consumption (close to the ratio of groundnut oil).

Cottonseed oil is also further refined for use in soaps and cosmetics. The five largest producers of cottonseed oil over the period 1995-2003 accounted for a combined 70% of global output. They relative shares were, China: 27%, United States: 12%, Former Soviet Union: 10%, India: 11%, Pakistan: 9%.

Figure-2

Uses of cottonseeds



Source: Adapted from: "Cotton Facts", ICAC (2003)

After the oil has been extracted from the cottonseed, the residue (i.e. cottonseed meal) is high in proteins (about 40%). It is usually marketed for animal feed, although it can have other usages (figure - 2). It is thus evident from above that even a cash GM crop like cotton can play a significant role in food security by:

i. Sparing cultivable land for other food crops due to increased productivity per hectare.

ii. Providing alternate and assured source of edible oil thereby saving precious foreign exchange required for edible oil imports.

iii. The surplus income to the farmer will increase his living standards and reach to better quality food.

iv. Better farm yield result in reduction in poverty which has direct relationship with the food security.

4.3 Environmental Impacts from Changes in Insecticide and Herbicide Use

GM crops have contributed to a significant reduction in the global environmental impact of production agriculture (Table-10). Since 1996, the use of pesticides was reduced by 172 million kg (a 6% reduction), and the overall environmental footprint from GM crops was reduced by 14%. In absolute terms, the largest environmental gain has been associated with the adoption of GM HT soybeans and reflects the large share of global soybean plantings accounted for by GM soybeans.

Table - 10.

Impact of changes in the use of herbicides and insecticides from growing GM crops globally, 1996-2004.

Trait	Change to pesticide use (million kg)	% change in pesticide (active ingredient) use
GM HT soybeans	-41.4	-3.8
GM HT maize	-18.0	-2.5
GM HT cotton	-24.7	-14.5
GM HT canola	-4.8	-9.7
GM IR maize	-6.3	-3.7
GM IR cotton	-77.3	-14.7
Totals	-172.5	-6.3

HT = herbicide tolerant,
IR = insect resistant,
Others = Virus-resistant papaya and squash, root worm-resistant maize.

Source: *http://www.agbioforum.org*

The volume of herbicide use in GM soybeans decreased by 41 million kg since 1996 (a 4% reduction), and the overall environmental footprint decreased by 19%. It should be noted that in some countries, such as in South America, the adoption of GM HT soybeans has coincided with increases in the volume of herbicides used relative to historic levels. This largely reflects the facilitating role of the GM HT technology in accelerating and maintaining the switch away from conventional tillage to no-or low-tillage production systems with their inherent environmental benefits. This net increase in the volume of herbicides used should, therefore, be placed in the context of the reduced GHG emissions arising from this production system change and the general dynamics of agricultural production system changes.

Major environmental gains have also been derived from the adoption of GM insect resistant (IR) cotton. These gains were the largest of any crop on a per hectare basis. Since 1996, farmers have used 77 million kg less insecticide in GM IR cotton corps (a 15% reduction). Important environmental gains have also arisen in the maize and canola sectors. In the maize sector, pesticide use decreased by 24 million kg. In the canola sector, farmers reduced herbicide use by 5 million kg (a 10% reduction).

4.4 Impact on greenhouse gas emissions

Reductions in the level of GHG emissions from GM crops derive from two principal sources:

i. GM crops contribute to a reduction in fuel use due to less-frequent herbicide or insecticide applications and a reduction in the energy use in soil cultivation.

ii. The use of no-till and reduced-till farming systems increase the amount of organic carbon in the form of crop residue that is stored or sequestered in the soil. This carbon sequestration reduces carbon dioxide emissions to the environment.

4.5 Biosafety: issues and concerns

i. **Allergenicity.** As a matter of principle, the transfer of genes from commonly allergenic foods is discouraged unless it can be demonstrated that the protein product of the transferred gene is not allergenic. While traditionally developed foods are not generally tested for allergenicity, protocols for tests for GM foods have been evaluated by the Food and Agriculture Organization (FAO) and World Health Organization (WHO) of the United Nations. No allergic effects have been found relative to GM foods currently on the market.

ii. **Gene transfer.** Gene transfer from GM foods to cells of the body or to bacteria in the gastro-intestinal tract would cause concern if the transferred genetic material adversely affects human health. This would be particularly relevant if antibiotic resistance genes, used in creating GMOs, were to be transferred. Although the probability of transfer is low, the use of technology without antibiotic resistance genes has been encouraged by a recent FAO/WHO expert panel.

iii. **Out-crossing.** The movement of genes from GM plants into conventional crops or related species in the wild (referred to as "out-crossing"), as well as the mixing of crops derived from conventional seeds with those grown using GM crops, may have an indirect effect on food safety and food security. This risk is real, as was shown when traces of a maize type which was only approved for feed use appeared in maize products for human consumption in the United States of America. Several countries have adopted strategies to reduce mixing, including a clear separation of the fields within which GM crops and conventional crops are grown.

WHO is undertaking an active role in relation to GM foods, primarily for two reasons:

i. on the grounds that public health could benefit enormously from the potential of biotechnology, for example, from an increase in the nutrient content of foods, decreased allergenicity and more efficient food production; and

ii. based on the need to examine the potential negative effects on human health of the consumption of GM food at the global level.

It is clear that modern technologies must be thoroughly evaluated if they are to constitute a true improvement in the way food is produced. Such evaluations must be holistic and all-inclusive, and cannot stop at the previously separated, non-coherent systems of evaluation focusing solely on human health or environmental effects in isolation.

Work is therefore under way in WHO to present a broader view of the evaluation of GM foods in order to enable the consideration of other important factors. This more holistic evaluation of GM crops and GM products will consider not only safety but also food security, social and ethical aspects, access and capacity building. International work in this new direction presupposes the involvement of other key international organizations in this area.

However, as the Brundtland Commission Report cautioned as early as 1987, the challenge of improving food security is more than just increasing food production.

4.6 Corporate Control

It is very unfortunate that the decision of whether this technology is going to be further developed and transferred to the small farmer is not in the hands of people in the developing world but in those of large multinational companies and the consumers and governments of developed countries (refer para. 1.9).

The public sector is a competent, but largely unproven, player for GM crop production in developing countries. Greater attention is needed for specific events where resources and knowledge are lacking to complete efficacy and safety testing. Otherwise, GM crops will remain in preliminary testing. Policy, research and regulatory options are needed to expedite regulatory decisions and testing of public GM crops. The sooner such evaluations occur, the faster GM crops unsuitable for field application can be discarded and successful GM crops moved forward, thus saving public funds and minimizing opportunity costs.

4.7 Regulation of GM crops in India

In India, the Ministry of Environment & Forests, Government of India notified the rules and procedures for the manufacture, import, use, research and release of GMOs as well as products made by the use of such organisms on December 5, 1989 under the Environment (Protection) Act, 1986 (EPA). These rules and regulations, commonly referred as Rules 1989 cover areas of research as well as large scale applications of GMOs and its products. These Rules are implemented by the Ministry of Environment & Forests and the Department of Biotechnology, Government of India. Six Competent Authorities and their composition have been notified under these Rules which are as follows:

i. **Recombinant DNA Advisory Committee (RDAC)**

ii. **Institutional Biosafety Committees (IBSC)**

iii. **Review Committee on Genetic Manipulation (RCGM)**

iv. **Genetic Engineering Approval Committee (GEAC)**

v. **State Biosafety Coordination Committees (SBCC)**

vi. **District Level Committees (DLC).**

While the RDAC is of advisory in function, the IBSC, RCGM, and GEAC are of regulatory in function, SBCC and DLC are for monitoring purposes.

Recombinant DNA Advisory Committee (RDAC)

This committee constituted by the Department of Biotechnology takes note of developments in biotechnology at national and international levels. The RDAC recommendations include, from time to time, the technologies/processes suitable for implementation for upholding the safety regulations in research and applications of GMOs and products thereof. This Committee prepared the Recombinant DNA Biosafety Guidelines in 1990, which was adopted by the Government for conducting research and handling of GMOs in India.

Institutional Biosafety Committee (IBSC)

It is necessary that each institution intending to carry out research activities involving genetic manipulation of microorganisms, plants or animals should constitute the IBSC. All the IBSCs, inter alia, need to have one nominee from the DBT. The IBSC is the nodal point for interaction within the institution for implementation of the guidelines. The main activities of IBSCs are:

i. To note and to approve r-DNA work.

ii. To ensure adherence of r-DNA safety guidelines of government.

iii. To prepare emergency plan according to guidelines.

iv. To recommend to RCGM about category III risk or above experiments and to seek RCGM's approval.

v. To inform DLC and SBCC as well as GEAC about the experiments wherever needed.

vi. To act as nodal point for interaction with statutory bodies.

vii. To ensure experimentation at designated locations, taking into account approved protocols.

Review Committee on Genetic Manipulation (RCGM)

The RCGM functions as a body under the Department of biotechnology and has the following functions:

i. To bring out manuals of guidelines, specifying producers for regulatory process on GMOs in research, use and applications including industry with a view to ensure environmental safety.

ii. To review all on going r-DNA projects involving high risk category and controlled field experiments.

iii. To lay down producers for restriction or prohibition, production, sale, import & use of GMOs both for research and applications.

iv. To permit experiments with category III risks and above with appropriate containment.

v. To authorize imports of GMOs/ transgenes for research purposes.

vi. To authorize field experiments in 20 acres in multi-locations in one crop season with up to one acre at one site.

vii. To generate relevant data on transgenic materials in appropriate systems.

viii. To undertake visits of sites of experimental facilities periodically, where projects with biohazard potentials are being pursued and also at a time prior to the commencement of the activity to ensure that adequate safety measures are taken as per the guidelines.

Genetic Engineering Approval Committee (GEAC)

This functions as a body under the Ministry of Environment and Forests and is responsible for approval of activities involving large scale use of hazardous microorganisms and recombinant products in research and industrial production from the environment angle. GEAC, inter alia, has the following functions:

i. To permit the use of GMOs and products thereof for commercial applications.

ii. To adopt producers for restriction or prohibition, production, sale, import & use of GMOs both for research and applications under Environment (Protection)Act, 1986.

iii. To authorize large-scale production and release of GMOs and products thereof into the environment.

iv. To authorize agencies or persons to have powers to take punitive actions under the under Environment (Protection)Act, 1986.

State Biotechnology Coordination Committee (SBCC)

It is constituted in each State where research and applications of GMOs are contemplated. SBCC is headed by the Chief Secretary of the State and has the following functions:

i. Powers to inspect, investigate and to take punitive action in case of violations of statutory provisions through the State Pollution Control Board or the Directorate of Health etc.

ii. To review periodically the safety and control measures in various institutions handling GMOs.

iii. To act as nodal agency at State level to assess the damage, if any, due to release of GMOs and to take on site control measures.

iv. The Committee coordinates the activities related to GMOs in the State with the Central Ministries. This committee also nominates State Government representatives in the activities requiring field inspection of activities concerning GMOs.

District Level Committee (DLC)

This Committee, constituted at the district level, is considered to be smallest authoritative unit to monitor the safety regulations in installations engaged in the use of GMOs in research and applications.

The DLC is headed by the District Collector who can induct representatives from State agencies to enable smooth functioning and inspection of the installations with a view to ensure the implementation of safety guidelines while handling GMOs, under the Indian EPA. Its functions are:

i. To monitor the safety regulations in installations.

ii. Have powers to inspect, investigate and report to the SBCC or the GEAC about compliance or non compliance of r-DNA guidelines or violations under EPA.

iii. To act as nodal agency at District level to assess the damage, if any, due to release of GMOs and to take on site control measures.

In addition, Monitoring and Evaluation Committee set up by RCGM visits field trial sites and recommends safe and agronomically viable transgenic crops to RCGM/GEAC.

The notification orders compliance of the safeguards through voluntary as well as regulatory approach and any violation and non-compliance including non-reporting of the activity in this area would attract punitive actions provided under the EPA.

The approvals and prohibitions under Rules 1989 are summarized below:

i. No person shall import, export, transport, manufacture, process, use or sell any GMOs, substances or cells except with the approval of the GEAC.

ii. Use of pathogenic organisms or GMOs or cells for research purpose shall be allowed under the Notification, 1989 of the EPA, 1986.

iii. Any person operating or using GMOs for scale up or pilot operations shall have to obtain permission from GEAC.

iv. For purpose of education, experiments on GMOs IBSC can look after, as per the guidelines of the Government of India.

v. Deliberate or unintentional release of GMOs not allowed.

vi. Production in which GMOs are generated or used shall not be commenced except with the approval of GEAC

vii. GEAC supervises the implementation of rules and guidelines.

viii. GEAC carries out supervision through SBCC, DLC or any authorized person.

ix. If orders are not complied, SBCC/DLC may take suitable measures at the expenses of the person who is responsible.

x. In case of immediate interventions to prevent any damage, SBCC and DLC can take suitable measures and the expenses incurred will be recovered from the person responsible.

xi. All approvals shall be for a period of 4 years at first instance renewable for 2 years at a time.

xii. GEAC shall have powers to revoke approvals in case of:

   a. Any new information on harmful effects of GMOs.

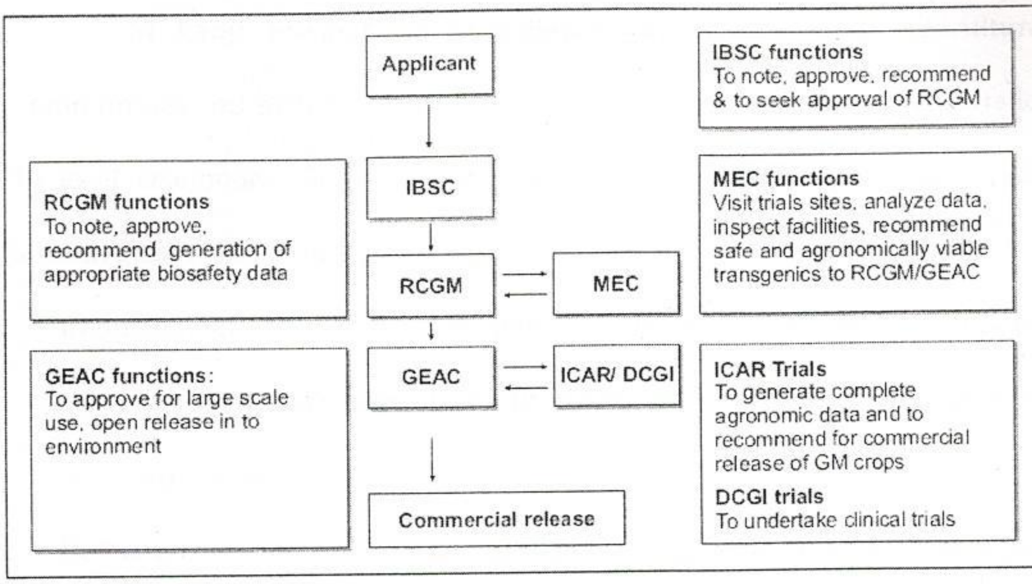
   b. GMOs cause such damage to the environment as could not be envisaged when approval was given.

   c. Non-compliance of any conditions stipulated by GEAC.

The procedures involved in the approval of GMOs in India are summarized in figure-3.

Figure-3

The procedures involved in the approval of GMOs in India



Source: Ministry of Environment and Forests. GoI.

Conclusions:

GM Crop research could enhance quality of life in agricultural communities and includes research on many basic food staples of importance to local economies. Some of the GM crops being developed could yield several quality of life improvements:

i. Reduction in the use of conventional pesticides, which has quantifiable environmental and human health benefits, as well as a reduction in application costs per acre.

ii. Reduction in the use of other agrochemicals widely used to fight virus, fungus or other diseases.

iii. Improved abiotic stress crop tolerance, such as drought and salinity that place limitations on poor farmers located in less favored regions.

iv. Better product quality, such as prolonged shelf life or enhanced product characteristics (foods delivering alternative carbohydrate or fat composition) that would improve transportation and consumer appeal of crops. The others are for product characteristics, such as increased sucrose.

v. There are also major public initiatives, such as HarvestPlus, that seeks to reduce micronutrient malnutrition to breed nutrient- dense staple foods.

vi. Alternative and more efficient provision of essential vitamins and vaccines.

A major advantage of plant biotechnology is that it often generates strategies for crop improvement that can be applied to many different crops.

Genetically engineered virus resistance, insect resistance, and delayed ripening are good examples of strategies that could potentially benefit a diversity of crops.

A second advantage of plant biotechnology in so far as feeding the developing world is that in principle it does not require major changes in the agricultural practices of small farmers. To date, most of the developments in plant gene transfer technology and the different strategies to produce improved transgenic plant varieties have been driven by the economic value of the species or the trait.

5. Recommendations and Prospects & Priorities for Future Studies

5.1 Recommendations

The major recommendations that emerged from this study are given below:

1) India should promote genomics and transgenic research and development keeping in view the short-term and long-term requirements of the nation, besides maintaining the global competitiveness in agriculture. The vast plant, animal and microbial biodiversity should be mined for genes of importance to sustain advances in crop and animal productivity. The transgenic approach must be judiciously integrated into the crop breeding programmes based on specific needs, particularly in cases where conventional breeding is not feasible or effective.

2) For effective utilisation of the technological, financial and human resources in the public sector, it may be useful to identify priorities for transgenic research and development based on objective criteria. Besides technology development for public good, the public sector institutions must play a vital role with regard to knowledge generation so as to fill the critical gaps in relation to transgenic development. Technology generation and capitalizing on the available technologies should go hand-in-hand.

3) In terms of the area under transgenic crops worldwide, herbicide tolerance as a trait ranks first. Although, herbicide tolerant transgenics offer specific advantages, in the Indian context it is not, at present, a priority trait, since,

it is preferable to adopt technologies that are labour-diversifying rather than those that could be labour displacing. Also, while setting priorities for transgenic research and development, it is important to consider the social dimensions, including employment impact, besides environmental impact.

4) The coming years will witness the use of food and non-food transgenic plants as vehicles for mass production of novel vaccines, antibodies and other therapeutic proteins. During production and commercialization of the pharma-transgenic crops it should be ensured that they do not contaminate the food chain. Appropriate guidelines should be formulated for production and handling of the pharma-transgenic crops. The developments in medical or pharmaceutical biotechnology utilizing crop plants as vehicles should be monitored and the linkages with agriculture, analyzed.

5) Although, there is no scientific evidence of the adverse environmental effects of selectable markers (like antibiotic resistance genes) that are widely used during transgenic development, research efforts on developing and utilizing 'clean gene' technologies or marker-free transgenics should be strengthened.

6) A transgene that has already undergone extensive biosafety tests should not be treated as new, even if it is a new transgenic event.

7) The toxicity and allergenicity tests for the transgenics should be prescribed on a case-by-case basis, based on the transgene, the crop and the economic

product(s). Institutions with relevant expertise and facilities should be identified, upgraded, accredited and networked for enhancing the efficiency of biosafety evaluation of the transgenics. The scientific data coming from reputed national/international institutions must be duly considered for testing toxicity and allergenicity.

8) The major environmental concerns arising from the possible release of transgenics should be evaluated on a case-by-case basis depending upon the gene, the crop, the trait and the target geographical location(s). The priorities and parameters of environmental impact assessment of the transgenics should be identified so that empirical data are generated on specific aspects (like gene flow and transgene invasiveness) through well-designed experiments proactively initiated by the scientific organisations. It is also important to strengthen the institutional mechanisms for analyses of the environmental/ecological effects of the transgenics.

9) Researchers/institutions involved in transgenic R&D must consider the implications of the IPRs related to the transgenics, particularly in the context of commercialization. It may be useful to establish a single window advisory service in India, for providing advice on IPRs pertaining to a transgenic project before its initiation.

10) To effectively translate the potential transgenic events into commercially viable products, the following approaches may be considered:

   a. In the public sector institutions, transgenic development and deployment should be undertaken through a cohesive research programme in two phases. The funding agencies must ensure that the project is in a network mode with relevant expertise and intra- and inter-institutional linkages before approval. Funding for Phase I should cover all aspects related to technology development. After the review committee certifies the success of Phase I, funds for Phase II (testing and commercialization) should be automatically released.

b. Public sector may demonstrate a 'robust' transgenic line at the greenhouse level, and find an industry partner, wherever appropriate, for effectively taking it through commercialization, including regulatory trials, value capture and sharing mechanisms.

c. Public and private sector may join for developing a transgenic product concept and together seek resources for undertaking the project with a clean value-sharing arrangement.

13) There is need for launching a genetic literacy movement in schools and colleges on the rapid developments taking place in the area of molecular genetics and genomics, so that there is a better understanding in the country of the opportunities and risks associated with recombinant DNA technology. This will help to promote the safe and responsible use of the tools associated with the new genetics in the country in the fields of food and agriculture, medicine, industry and the environment.

5.2 *Policy and regulation*

To democratize biotechnology for development, a number of policy aspects need to be rethought in fundamental ways. These include:

I. encouraging greater involvement of technology users and consumers in the framing of research and establishing development priorities

II. Revitalizing public sector research and development in agriculture, with a focus on technology development for low cost, high employment, small-scale agriculture

III. Rethinking regulation in a way that will reflect local priorities and will hold the public and private sectors to account

IV. Reflecting local priorities in new trade, regulatory and intellectual property models

V. Facilitating wider and more inclusive discussions - among marginalized people elite groups - in setting future directions for science, technology and development.

5.3 Future prospects

Whatever the social, economic and environmental impact of these new technologies, it is already clear that a number of developing countries — particularly China, India, South Africa and Brazil — have already developed the scientific and technical capacity to play a leading role in biotechnology research, and thus in shaping GM technology to their own requirements.

In fact, some developing countries have been among the most enthusiastic in adopting GM crops. So far, however, the fact that globally, most agronomic GM research has been carried out either by the private sector, or by government laboratories in developed countries, means that it has inevitably focused on crops important to commercial farmers and Industrialised agriculture in these regions.

The focus, so far, has been on just four crops – maize, cotton, canola (rape) and soyabean – and two traits, insect resistance and herbicide tolerance. Relatively little attention has been paid to crops such as sorghum, millet and traits such as drought resistance, water use efficiency, salinity tolerance *etc* which are of more interest to the developing world.

GM Crops have a valuable role to play in addressing the challenge of water scarcity in developing countries. However, many applications of biotechnology in this area have not yet met their full potential to deliver practical solutions to the end-user in developing countries.

Reflecting this imbalance, many development activists and civil society groups believe that the promotion of GM crops by multinational companies undermines both the food security of the poor and the economic interests of developing countries. Others focus on supporting the efforts of public, private and non-profit agencies – such as the members of the World Bank's Consultative Group on International Agricultural Research (CGIAR) – to develop and deliver GM technology in ways that are more pro-poor.

Not withstanding its attendant challenges and alternatives, the GM crop movement shows great promise. Like the Green Revolution before it, the GM crop movement has the potential to achieve substantial production increases in regions of need and (unlike the Green Revolution) to reduce the need for agricultural chemicals and scarce resources, such as water. Both the successes and failures of the Green Revolution provide useful lessons for how to make GM crop technology a desirable and sustainable agricultural movement in the developing world.

The Green Revolution demonstrates that to create GM crops that are truly beneficial to the developing world, plant breeders and other scientists must be familiar with the local environment and the planting methods of the region for which they are developing crops. At times, agricultural conditions in developing regions are so different from those in the industrial world that it is difficult for scientists to know how to devise appropriate technologies and practices for those regions.

During the Green Revolution, plant scientists traveled extensively, and acquired training in developing crop seeds that were best suited to particular regions given their particular weather conditions, plant pests, water availability, and planting seasons. Importantly, these plant scientists trained others in each region to be able to carry out the Green Revolution practices independently. The same sort of global effort is needed for the Gene Revolution to take hold in the developing world. Moreover, retention of this trained scientific manpower in public sector research agencies is also required to :

i. Have research and development to suit the needs of our region in order to develop crops which meet local requirements and target poverty elevation.
ii. Avoid brain drain.

iii. Implement the regulatory regime successfully through knowledge and initiative.

5.4 Scope for future study

The study fell short in identifying the role of cottonseed oil in food security and the effect of the Bt cotton in the same. Moreover, effect of the Bt gene on the consumption of cottonseed oil could not be studied in the short duration of the study period.

A detailed analysis of reasons for delay in release of the other GM food crops in India also could not be made due to reasons explained above. Role of NGOs and PPP in successful commercial use of GM crops with an aim to meet the MDG need to be carried out in future. **Keeping in view the importance of the subject there is a need to take up the study, on future and impact of GM food crops in India, in detail.**

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