A SEMINAR PAPER ON

Genetically Modified Crops: Promises and Problems in Modern Agriculture

Course Title: Seminar

Course Code: GPB 598

Term: Summer, 2018

SUBMITTED TO:

Course Instructors

1. Dr. Md. Mizanur Rahman
   Professor
2. Dr. A. K. M. Aminul Islam
   Professor
3. Dr. Md. Rafiqul Islam
   Professor
4. Dr. Dinesh Chandra Shaha
   Assistant Professor

Major Professor

Dr. Nasrin Akter Ivy

Professor

Department of Genetics and Plant Breeding

BSMRAU

SUBMITTED BY:

Shafia Mashiat

MS Student

Reg. No: 13-05-2927

Department of Genetics and Plant Breeding

BANGABANDHU SHEIKH MUJIBUR RAHMAN AGRICULTURAL UNIVERSITY
SALNA, GAZIPUR

ABSTRACT

Since 1973 by development of DNA recombination technology, advancements in modern agriculture science and technology have brought about the current Genetically Modified (GM) crop revolution. GM crops are promising to mitigate current and future problems in modern agriculture. Genetically modified crop has become a argumentative subject as its benefits for both food producers and consumers arecompaniedbypotentialbiomedicalrisks and environmental side effects. The production of GM crops is increased day by day for their numerous benefits.The genetic modification in crops express many traits, such as, increasing yield, higher vitamin and micronutrient content, resistance to insect, diseases and pests, longer shelf-life for and so on. The principal GM crops grown commercially in field are herbicide and insecticide resistant soybeans, maize, cotton and canola. Like all new technologies, they pose some risks, both known and unknown. Independent scientists, environmentalists, farmers and consumers who warn that genetically modified crop introduces new risks to food security, the environment and human health such as loss of biodiversity, the emergence of superweeds, the increase of antibiotic resistance, food allergies and other unintended effects. This paper reviews major viewpoints which are currently debated on benefits and risks of GM crops for human health, ecosystems and biodiversity. In this context, some regulations and precautions exist, which should be strictly applied for the safety of GM crops consumption.

Key words: Genetic Modification, DNA recombination, Transgene, Regulation, Food security

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Genetic Modification (GM) is the manipulation of the genetic material in living organisms, enabling them to perform specific functions (Raman, 2017). Genetically Modified Organism is defined as follows by WHO (World Health Organization): "Organisms (i.e. plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination" (WHO, 2016). With DNA recombinant technology, genes from one organism can be transferred into another, usually unrelated, organism. The developments leading to modern genetic modification took place in 1946 where scientists first discovered that genetic material was transferable between different species. This was followed by DNA double helical structure discovery and conception of the central dogma the transcription of DNA to RNA and subsequent translation into proteins by Watson and Crick in 1954. Consequently, a series of breakthrough experiments by Boyer and Cohen in 1973, which involved "cutting and pasting" DNA between different species using restriction endonucleases and DNA ligase - "molecular scissors and glue" successfully engineered the world's first GM organism. In agriculture, the first GM plants antibiotic resistant tobacco and petunia were successfully created in 1983 by three independent research groups. In 1990, China became the first country to commercialise GM tobacco for virus resistance. In 1994, the Flavr Savr tomato (Calgene, USA) became the first ever Food and Drug Administration (FDA) approved GM plant for human consumption. This tomato was genetically modified by antisense technology to interfere with polygalacturonase enzyme production, consequently causing delayed ripening and resistance to rot. Since then, several transgenic crops received approvals for large scale human production in 1995 and 1996. Initial FDA-approved plants included maize, cotton, potatoes, canola and soybeans (Bawa and Anilakumar, 2013). Currently, the GM crop pipeline has expanded to cover other fruits, vegetables and cereals such as lettuce, strawberries, eggplant, sugarcane, rice, wheat, carrots etc. with planned uses to increase vaccine bioproduction, nutrients in animal feed as well as confer salinity and drought resistant traits for plant growth in unfavourable climates and environment (Raman, 2017).

Throughout history, people's main concern was producing enough food. Civilization advanced as we developed agriculture. For 10,000 years scientists bred wild plants to produce more food with less work. Agriculture got a boost in the 1950s with new chemicals that control insects, weeds, and disease. At the same time, plant breeders developed more productive varieties of wheat, corn, and rice. Together, new farm chemicals and improved crops led to much higher yields (amounts produced). This increase in production was known as the "Green Revolution". Worse, many of the world's poor have never benefited from the Green Revolution because it did not solve the underlying problem: poverty. Many farmers can't afford the chemicals and improved seeds. Many scientists think a new "Gene Revolution" can help both hungry humanity and the sensitive environment. The Gene Revolution uses biotechnology to create new genetically modified or "GM" crops. These crops can potentially produce more food with fewer chemicals and higher nutritional value than traditional crops. Scientists think they can improve even more crops than the Green Revolution did not only grains, but also the legumes, vegetables, roots, and fruits that people need for a balanced, nutritious diet (Delude and Mirvis, 2000). Since their commercialisation, the global food crop yield (1996–2013) has increased by 370 million tonnes over a relatively small acreage area (Zhang et al., 2016). Furthermore, GM crops have been recorded to reduce environmental and ecological impacts, leading to increases in species diversity. Genetically modified (GM) crops had considerable potential to improve food security and the effectiveness of the agricultural sector in developing countries. Moreover they reduce costs for food production, reduce need for pesticides, enhance nutrient composition and food quality and resistance to pests and disease (Phillips, 2008). Nevertheless, advancements in GM crops have raised significant questions of their safety and efficacy. The GM seed industry has been plagued with problems related to human health and insect resistance which have seriously undermined their beneficial effects. Moreover, poor science communication by seed companies, a significant lack of safety studies and current mistrust regarding GMOs have only compounded problems. These have led many countries, particularly the European Union and Middle East to implement partial or full restrictions on GM crops (Raman, 2017). So, this study is done to know the promise, benefits and problems, besides precaution and regulation of GM crops.

Objectives:

1. To know about Genetically Modified crops and its necessity
2. To review the benefits and promise of genetically modified crops in modern agriculture
3. To understand the problems, precaution and regulation of genetically modified crops

CHAPTER II

MATERIALS AND METHODS

Scientific approach requires a close understanding of the subject matter. This paper mainly depends on the secondary data. Different published reports of different journals mainly supported in providing data in this paper. This paper is completely a review paper. Therefore no specific method has been followed in preparing this paper. It has been prepared by browsing internet, studying comprehensively various articles and research paper published in different journals, books, proceedings, dissertation available in the libraries of Bangabandhu Sheikh Mujibur Rahman Agricultural University. I would like to express deepest sense of gratitude to my major professor and course instructors for their efficient and scholastic guidance, precious suggestions to write this manuscript from its embryonic stage. All the information collected from the secondary sources have been compiled systematically and chronologically to enrich this paper.

CHAPTER III

RESULTS AND DISCUSSION

Genetically Modified Crops

Genetic modification is a biological technique that effects alterations in the genetic machinery of all kinds of living organisms. GM is a technology that involves inserting DNA into the genome of an organism. To produce a GM plant, new DNA is transferred into plant cells. Usually, the cells are then grown in tissue culture where they develop into plants. The seeds produced by these plants will inherit the new DNA.

History and Development of Genetically Modified Crops

The genesis of DNA modification technology can be traced back to 1946, when scientists discovered that genetic material can be transferred between different species (McCarty and Avery, 1946). Several hallmark papers paved the way to the modern science of molecular biology (Figure 1). In 1954, Watson and Crick discovered the double helix structure of DNA, and the "central dogma" DNA transcribed to messenger RNA, translated to protein was established. Nobel Laureate Marshall Nirenberg (Nirenberg et al., 1963) and others had deciphered the genetic code by 1963. In 1973, Cohen et al. developed DNA recombination technology, showing that genetically engineered DNA molecules can be transferred among different species. The first genetically modified plants antibiotic resistant tobacco and petunias were produced by three independent research groups in 1983. In 1994 the US market saw the first genetically modified species of tomato with the property of delayed ripening approved by the Food and Drug Administration (FDA). Since then, several transgenic crops have received FDA approvals (Bawa and Anilakumar, 2013).

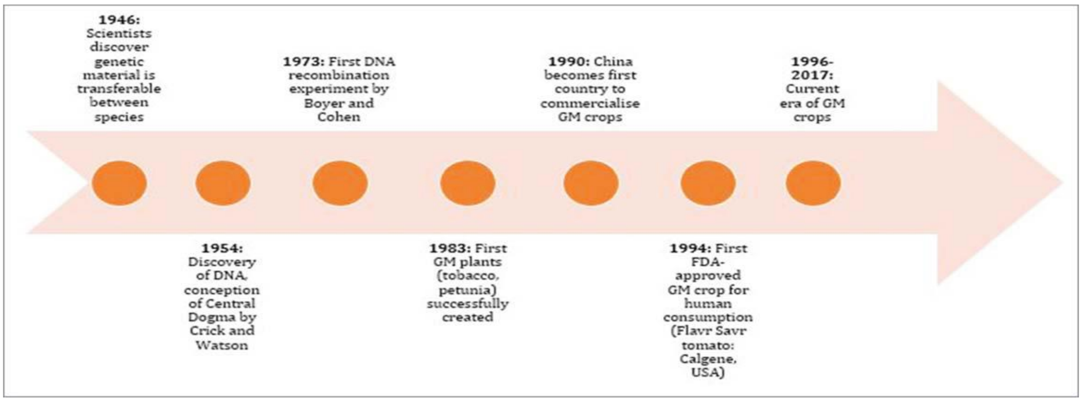

Figure 1. A timeline of events leading to the current GM crop era.

Source: **(**Raman, 2017)

Generation of GM crops

In order to generate GM crops, researchers need to introduce the gene(s) coding for certain traits into a plant cell, and then regenerate a plant through tissue culture. When and where the transferred gene is expressed is usually inherent in the scheme to optimize the property of the product (Zhang et al., 2016). The first stage in making a GM plant requires transfer of DNA into a plant cell. One of the methods used to transfer DNA is to coat the surface of small metal particles with the relevant DNA fragment, and bombard the particles into the plant cells. Another method is to use a bacterium or virus. There are many viruses and bacteria that transfer their DNA into a host cell as a normal part of their life cycle. For GM plants, the bacterium most frequently used is called *Agrobacterium tumefaciens*. The gene of interest is transferred into the bacterium and the bacterial cells then transfer the new DNA to the genome of the plant cells (Figure 2). The plant cells that have successfully taken up the DNA are then grown to create a new plant. This is possible because individual plant cells have an impressive capacity to generate entire plants.

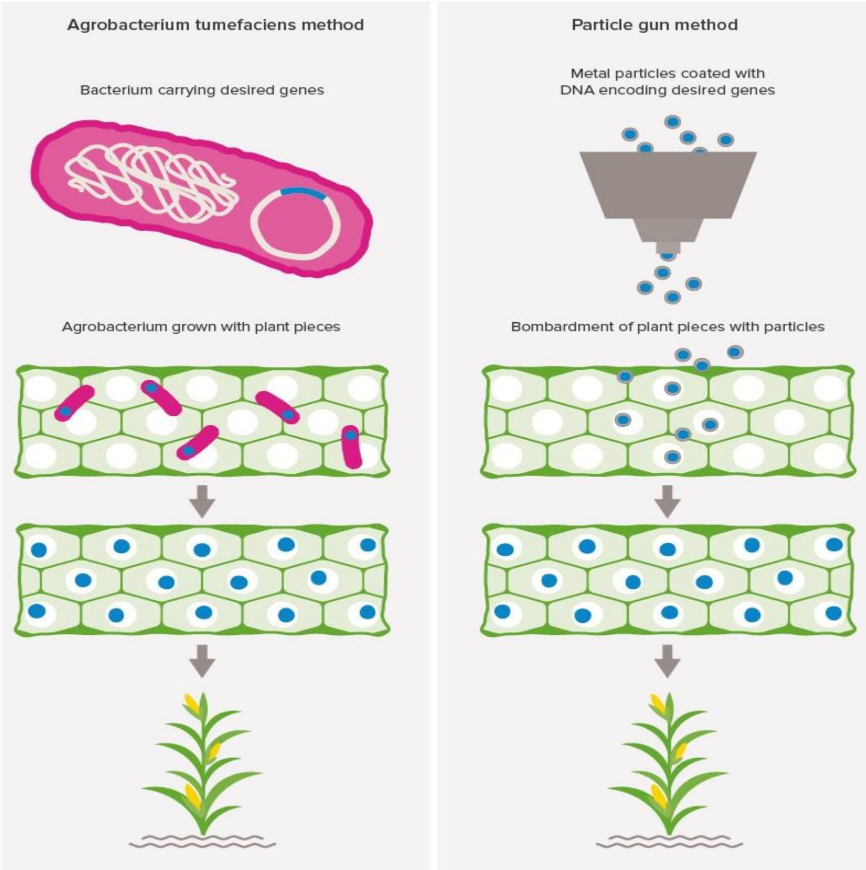

Figure 2. DNA Transfer Procedure.

Source: **(**The Royal Society, 2018)

The Need for GM Crops

Before starting discussing the merits and demerits of GM crops, it is important to set forth why there is such great effort to develop them. There are three major challenges we are facing that motivate our resort to the new technology for help.

A. Expansion of population:

The current global human population is approximately 7.35 billion. Although growth rate of the world population has slowed in recent years (1.24% per year 10 years ago versus 1.18% per year in recent years). The estimated global population will be 8.5 billion in 2030, and 9.7 billion in 2050 (Figure 3). In 2016, the U.N. Food and Agricultural Organization (FAO) reported that 795 million people in the world were undernourished, among which 780 million people in developing regions. Therefore the eradication of hunger should be a priority of policy-making. Arguably the most realistic solution for matching increased global demand for crops is to boost the crop yields on currently cultivated land. Currently, the rate of increase in crop-yield is less than 1.7% whereas the annual increase in yield needs to be 2.4% to meet the demands of population growth, improved nutritional standards and decreasing arability (Ray et al., 2013). This is a daunting task, which seems only achievable by means of optimization of crop genetics coupled with quantitative improvements in management of the agricultural system.

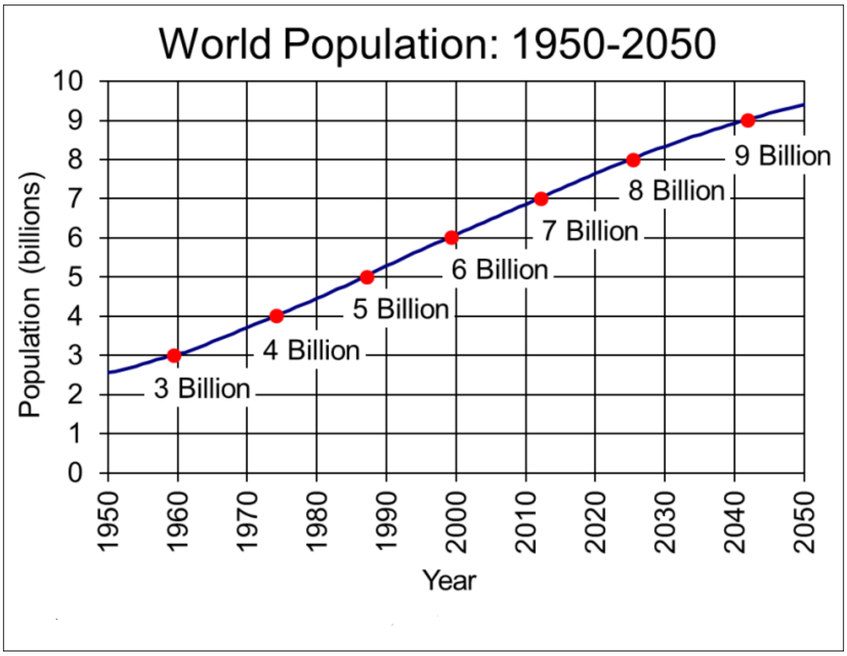

Figure 3. Projected global population growth through to 2050.

Source: (Us census Bureau, international database, 2016).

B. Decrease in arable land:

FAO predicted that the finite amount of arable land available for food production per person will decrease from the current 0.242 ha to 0.18 ha by 2050 (Figure 4) (Alexandratos and Bruinsma, 2012). This problem confounds those of population growth and malnutrition. The alternative is greater yield per acre, which in turn must come from greater agriculture inputs, such as fertilizer, water, pest and weed control and/or genetic improvement. This scenario is compounded by several complicating factors: (1) the increased demand for biofuel and feedstock production; (2) accelerated urbanization; (3) land desertification, salinization, and degradation; (4) altered land use from staple foods to pasture, driven by socioeconomic considerations; (5) climate change; (6) water resource limitation.

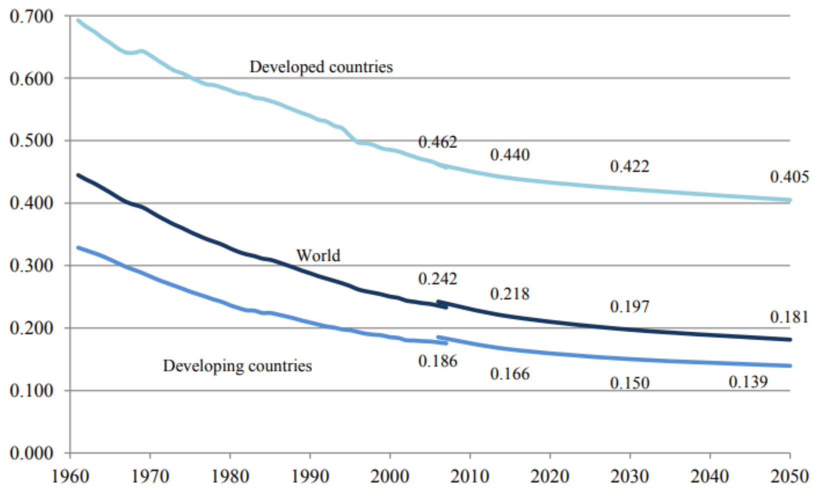

Figure 4. Arable land per capita (ha in use per person).

Source: (Alexandratos and Bruinsma, 2012)

C. Bottleneck of conventional and modern breeding:

Conventional breeding relies on sexual crossing of one parental line with another parental line, in hopes of expressing some desired property (e.g. disease resistance). To select for the desired trait and to dilute irrelevant or undesired traits, breeders choose the best progeny and back-cross it to one of its parents (plant or animal). The process usually takes several years (depending on generational time, e.g. 10–15 years for wheat) (Oliver, 2014). Taking these facts into account, the emergence of biological technologies and the development of GM foods promise to reduce dramatically production timelines to new strains, and to provide us with optional strategies to achieve sustainable global food security.

Popular traits:

Of some 30 traits that are currently engineered into plants for commercial use for example resistance against herbicide, insecticide, disease, insect, pest, improvement of micronutrient etc. (Figure 5). The most popular are those that confer herbicide tolerance and insect resistance.

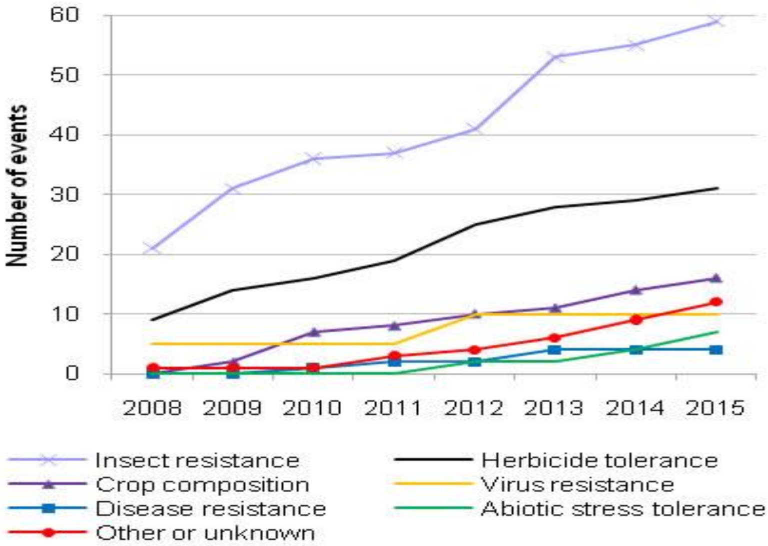

Figure 5. Number of events in GM crops worldwide, by trait.

Source: (Stein and Rodríguez-Cerezo, 2010)

- **Herbicide Resistane**

A transgene confers resistence to a specific herbicide. This character allows cultivar to appeal a herbicide which acts on a wide range of weeds but does not harm the GM crop. Herbicide tolerance is currently the most commonly used GM trait worldwide (Table 1), for example in soybean, maize, cotton and oil seed rape (Thomas et al., 2003). They comprised 83% of the total GM crop area, equating to just under 8% of the arable land worldwide. Most herbicide resistant GM crops have been engineered for glyphosate tolerance, in the USA 93% of soybeans and most of the GM maize grown is glyphosate tolerant (Green, 2014).

Table 1: List of Herbicide Tolerance Crops

GM Crops	Use	Countries Approved	First Approved
Cotton	Fiber	Argentina	2001
	Cottonseed oil	Australia	2002
	Animal feed	Brazil	2008
		India	2002
		Paraguay	2013
		South Africa	2000
		USA	1994
Maize	Animal feed	Argentina	1998
	High fructose corn syrup	Brazil	2007
	Corn starch	Canada	1996
		Paraguay	2012
		South Africa	2002
		USA	1995
Soybean	Animal feed	Argentina	1996
	Soybean oil	Brazil	1998
		Chile	2007
		Mexico	1996
		USA	1993
Sugarbeet	Food	Canada	2001
		USA	1998
Alfalfa	Animal feed	USA	2005
Canola	Cooking oil	Australia	2003
	Margarine emulsifiers in packaged foods	USA	1995

Source: (ISAAA, 2016)

❖ **Insect/pest resistance**

A transgene produces toxins to specific insects that feed on the crop. Such genes have been widely used and are already leading to substantial reductions in the use of pesticides and insecticides (Table 2) (Thomas et al., 2003). Most currently available genes used to engineer insect resistance come from the *Bacillus thuringiensis* bacterium. Insect resistant crops target various species of coleopteran (beetles) and lepidopteran (moths) (Fleischer et al., 2014). Insect-resistant cotton, maize and potato varieties are being grown in both developed and developing countries.

Table 2: List of Insect Resistance GM Crops

GM Crops	Use	Countries Approved	First Approved
Cotton	Fiber	Argentina	1998
	Cottonseed oil	Australia	2003
	Animal feed	Brazil	2005
		China	1997
		India	2002
		South Africa	1997
		Sudan	2012
		USA	1995
Eggplant	Food	Bangladesh	2013
Maize	Animal feed	Argentina	1998
	High fructose corn syrup	Brazil	2005
	Corn starch	Mexico	1996
		Paraguay	2007
		South Africa	1997
		USA	1995
Poplar	Tree	China	1998

Source: (ISAAA, 2016)

- **Bacterial, fungal and viral resistance**

Here a transgene makes crops resistant to biotic stresses such as plant pathogens which often reduce yields substantially. In case of Virus resistance crops, the transgene prevents the virus from replicating successfully in the host plant. Commercially grown VR varieties of papaya were first introduced in the state of Hawaii in 1998. VR squash production began in the United States in the late 1990s. China approved commercial production of VR sweet pepper (*Capsicum annuum*) in 1998 (National Academies of Sciences, Engineering, and Medicine, 2016).

- **Abiotic stress resistance**

The ability of some plants to survive in harsh climatic or soil conditions such as drought, heat, frost and acidic or salty soils is sometimes associated with specific groups of genes. These genes can be isolated and introduced into crops. Research on crops such as cotton, coffee, rice, wheat, potato, *Brassica*, tomato and barley varieties is currently in different stages of completion.

- **Micronutrient enrichment**

In aiming to prevent malnutrition, GM crop could play a vital role in the provision of vitamins or minerals. GM crops could help to provide people with essential micronutrients through consumption of their main staple crop. Research in this area is currently being undertaken in rice, cassava, millet and potato (Table 3) (Thomas et al., 2003).

Table 3: List of GM Crops that nutritionally improved

Traits	Crops
Protein quality and level	Canola, Maize, Potato, Rice, Soybean, Sweet potato
Oils and fatty acids	Canola, Cotton, Linseed, Oil palm, Rice, Soybean, Safflower,
Carbohydrates	Maize, Potato, Sugarbeet, Soybean, Rice
Vitamins and carotenoids	Rice, Maize, Mustard, Potato, Strawberry, Tomato,
Mineral availabilities	Rice, Maize, Lettuce, Soybean, Wheat

Source: (Newell-McGloughlin, 2008)

- **Other modified traits**

Some crops have been developed for other traits (Table 4). For example, soybean, efforts have been made to increase oxidative stability of the oil to avoid transfats generated through the hydrogenation process and to enhance omega-3 fatty acid content of the oil for use in both food and feed. In maize, GE traits have been developed for drought tolerance and increased alpha-amylase content. In 2015, nonbrowning varieties of apple and potato were sold commercially (National Academies of Sciences, Engineering, and Medicine, 2016).

Table 4: List of Crops of others modified traits

GM Crops	Use	Trait	Countries Approved	First Approved
Maize	Animal feed	Increased lysine	Canada	2006
	High fructose corn syrup		USA	2006
	Corn starch	Drought Tolerance	Canada	2010
			USA	2011
Papaya	Food	Virus Resistance	China	2006
			USA	1996
Potato	Food	Virus Resistance	Canada	1999
	Industrial		USA	1997
		Modified starch	USA	2014
Soybean	Animal feed	Increased oleic	Argentina	2015
	Soybean oil	acidproduction	Canada	2000
			USA	1997
		Stearidonic	Canada	2011
		acidproduction	USA	2011
Sugarcane	Food	Drought tolerance	Indonesia	2013
Squash	Food	Virus Resistance	USA	1994
Rose	Ornamental	Modified flower	Australia	2009
		colour	USA	2011
Canola	Cooking oil	High laurate canola	Canada	1996
	Margarine emulsifiers in		USA	1994
	packaged foods	Phytase production	USA	1998
		Delayed senescence	Australia	1995
			Norway	1998

Source: (ISAAA, 2016)

GM Crops Production

The total area of GM crops amounted to 175 million hectares by at the end of 2013 (Figure 6).

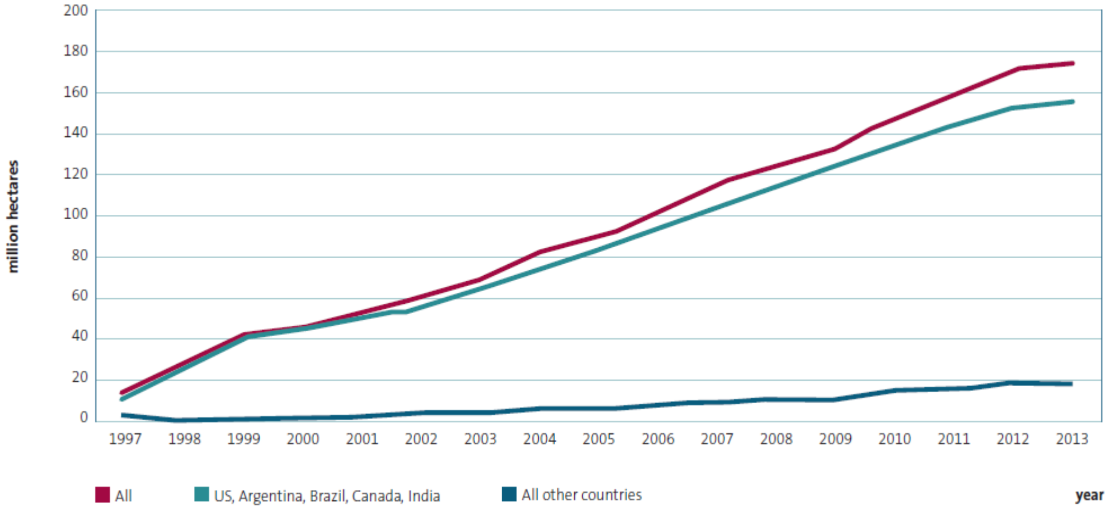

Figure 6. Global area of GM crops.

Source: (James, 2014).

The main growers of GM crops are the US, Brazil, and Argentina, while India, Canada and China also are important producers **(**Atici, 2014). GM crops are predominantly found in these six countries (92 per cent of GM crops) (Figure 7).

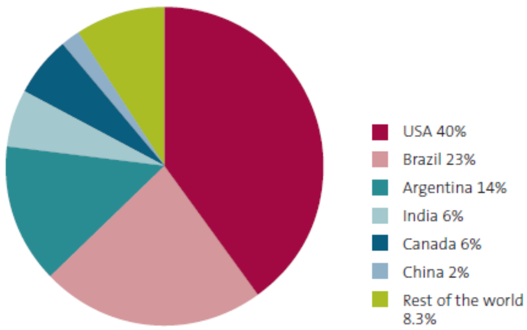

Figure 7. GM crop production of six countries.

Source: (James, 2014).

Currently just four crops – soybean (50%), maize (31%), cotton (14%) and canola (5%) account for 99% of global genetically modified crops (Figure 8) (Pispini et al., 2014)

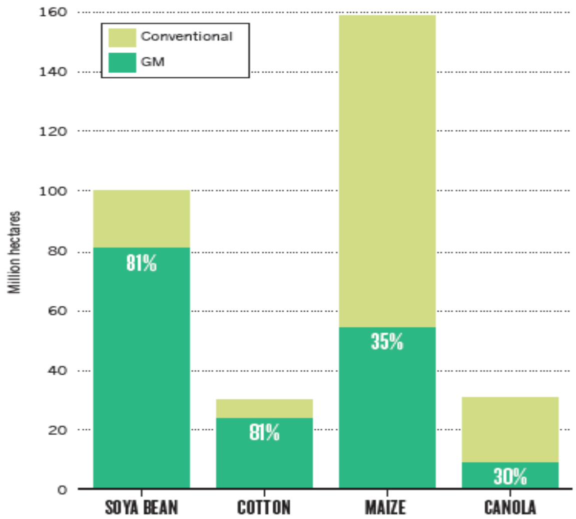

Figure 8. Popular most grown GM crops.

Source: (Gilbert, 2013)

GM Crops in Asia:

Production of GM crops is much lower in Asia than in North and South America. According to the ISAAA report, 19.1 million ha of GM crops were grown across five countries, India, China, Pakistan, the Philippines and Myanmar constituting 10.9 per cent of global GM crop production. The insect resistance is the dominant trait (Table 5). The most grown GM crop is insect resistant (Bt) cotton, which is the only GM crop grown in India, Pakistan and Myanmar, and the largest crop in China. Only the Philippines grows GM maize, which accounts for approximately 28 per cent of the national maize area. With respect to GM Cotton, India is the front runner with 10.8 million ha, accounting for 93 per cent of the total cotton area in India (Pispini et al., 2014).

Table 5: GM Crops in Asia

COUNTRY	PRODUCT	MILLION (ha)	TRAITS
India	Cotton	11	Insect resistant
China	Cotton, papaya, poplar trees	4.2	Insect resistant, Virus resistant
Pakistan	Cotton	2.8	Insect resistant
Philippines	Maize	0.8	Insect resistant, herbicide tolerant and stacked traits
Myanmar	Cotton	0.3	Insect resistant
Total		**19.1**	

Source: (Pispini et al., 2014)

Acceptance of GM Crops

Since the first GM crop approval in 1994, the increase in the number of approved GM crops has been relatively constant over the course of the past two decades (Figure 9). Different GM traits in various crops such as potato, canola, maize, cotton, and soybean have been approved worldwide. Besides the vast number of GM traits, the approval status of many GM crops varies from country to country.

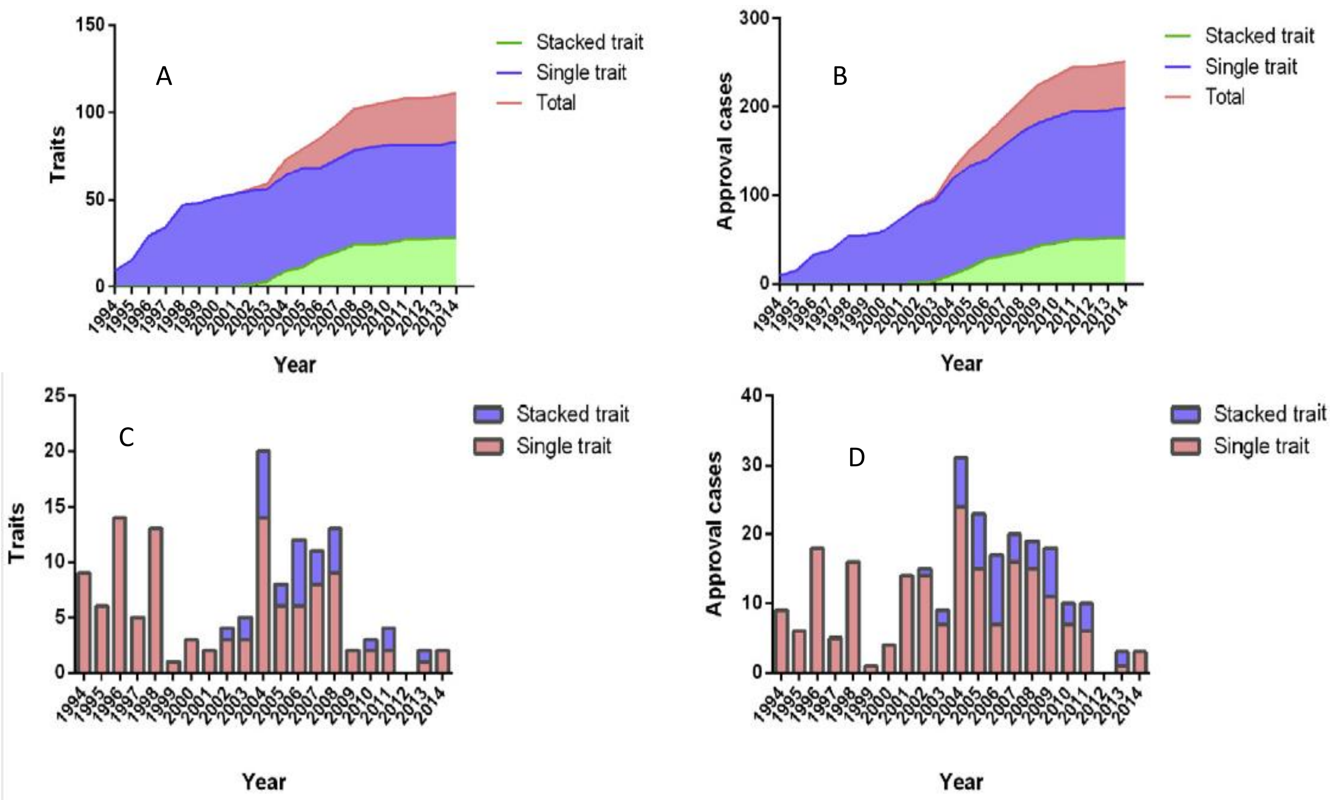

Figure 9. Annually introduced genetically modified (GM) crop traits and approval cases for food/feed use. (A) Accumulated GM crop traits. (B) Accumulated GM crop approval cases. (C) New GM crop traits introduced each year. (D) New approval cases introduced each year.

Source: (Lin and Pan, 2016)

Benefits of Genetically Modified Crops

1. **Reduction in Herbicide Use**

There has been a small net decrease in the amount of herbicide active ingredient used (−0.1%) in GM soybean, which equates to about 2.3 million kg less active ingredient applied to these crops than would otherwise have occurred if a conventional crop had been planted. In 2013, the reduction in herbicide usage in GM maize was just over 21.8 million kg of active ingredient (−9.8%). The use of GM cotton delivered a net reduction in herbicide active ingredient use of about 21.3 million kg over the 1996–2013 period. This represents a 7.2% reduction in usage (Table 6). In 2013, the use of GM cotton technology resulted in a 2.9 million kg reduction in herbicide active ingredient use (−5.6%). In 2013, the use of GM HT canola resulted in a 2.1 million kg reduction in the amount of herbicide active ingredient use (−17.1%).

Table 6: Herbicide use Changes in GM Crops

GM Crops	Change in active ingredient use (million kg)	% change in amount of active ingredient used
Soybean	−2.29	−0.1
Maize	−210.5	−9.3
Cotton	−21.3	−7.2
Canola	−18.4	−16.5

Source: (Brookes and Barfoot, 2015)

2. Reduction in Insecticide and Pesticide Use

The major advantage of Bt crops is the reduction in the levels of pesticides that used by cultivars. This can have considerable ecological benefits, as excessive use of pesticides can be harmful to the environment. There are also potential economic benefits in 2001, 20% of pesticides applied globally were used on cotton, at a total cost of US$1.7 billion**(**James,2002).Significant reductions can also have health-related benefits for farm workers who apply pesticides or insecticides, or who work in fields in which these have been. Such events were indicated to be reduced by 60%, compared with farmers who grow non-Bt cotton. The rate of use of insecticides applied to maize fell from 0.2 kg/ha in 1998 to about 0.05 kg/ha in 2011, a 75% decrease. The data indicate that nearly 50% of applied weight in insecticides took the form of seed treatments (Figure 10).

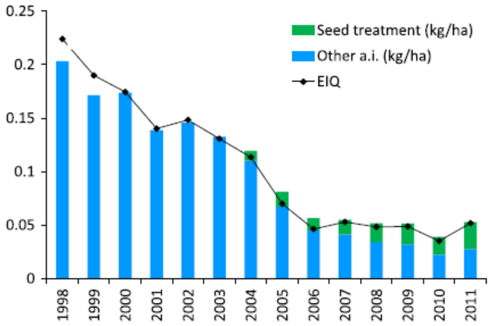

Figure 10. Insecticide use in maize (kg/ha and EIQ weights); (Environmental Impact Quotient =EIQ)

Source: **(**Perry et al., 2016)

The 2010 National Research Council report on impacts of GE crops in the United States reviewed data from USDA on insecticide use in cotton and maize from 1996 through 2007 and found a clear shape of decline in both crops in pounds of active insecticidal ingredient (a.i.) applied per acre. Fernandez-Cornejo et al. (2014) extended the assessment of USDA data through 2010 as illustrated in figure.

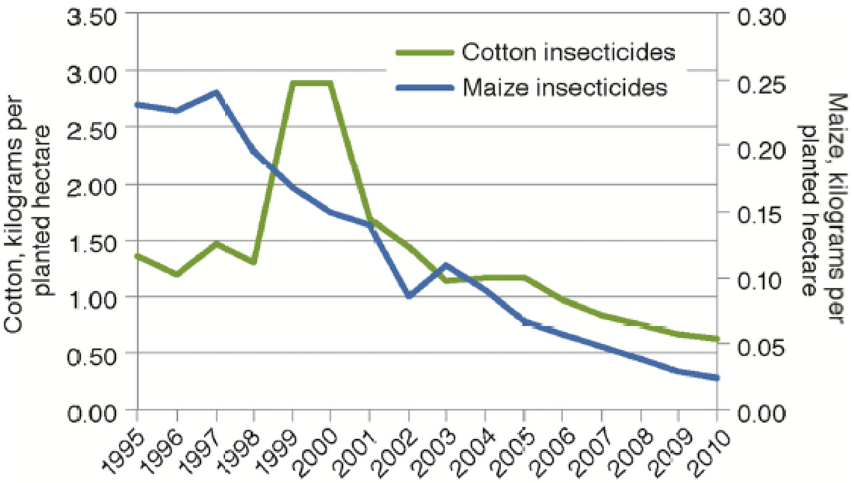

Figure 11. Rates of insecticide application for maize and cotton in the United States from 1995 to 2010.

Source: Fernandez-Cornejo et al. 2014

3. Increase Crop Yield

A report from Graham Brookes and Peter Barfoot arrived conclusion that for the period 1996–2013 it was estimated that biotechnology was responsible for additional global production of 138 million tons of soybeans, 274 million tons of corn, 21.7 million tons of cotton lint, and 8 million tons of canola (Zhang et al., 2016). GM technology has increased crop yields by 21% (Figure 12). These yield increases are not due to higher genetic yield potential, but to more effective pest control and thus lower crop damage (Qaim and Zilberman, 2003). Side by side, GM crops have minimized pesticide quantity by 37% and pesticide cost by 39%. The effect on the cost of production is not significant. GM seeds are more expensive than non-GM seeds, but the additional seed costs are compensated through savings in chemical and mechanical pest control. Average profit gains for GM-adopting farmers are 69%

.

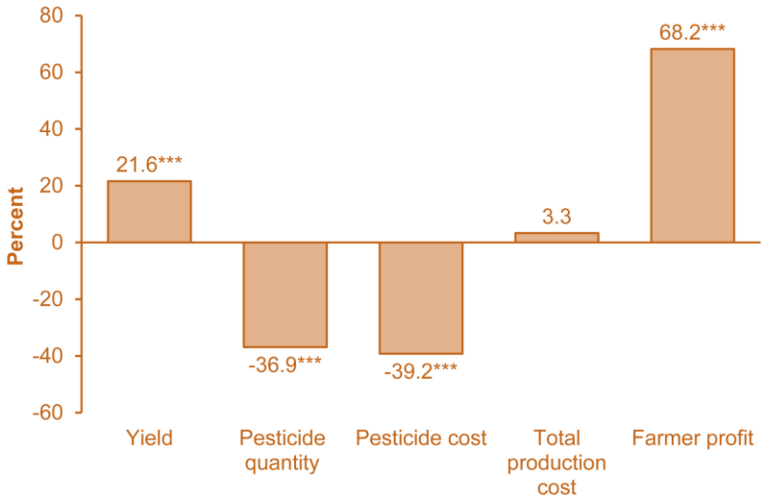

Figure 12. Incease in yield of GM crop.

Source: (Klumper and Qaim, 2014)

The figure 13 shows US soybean production in 5-year average blocks. The orange part of the bars shows how much of the production was possible using the yields seen in the late 70s, and the green part of the bars shows how much of the production was based on yield increases since that time. The rate of yield increase has accelerated since the introduction of biotech traits.

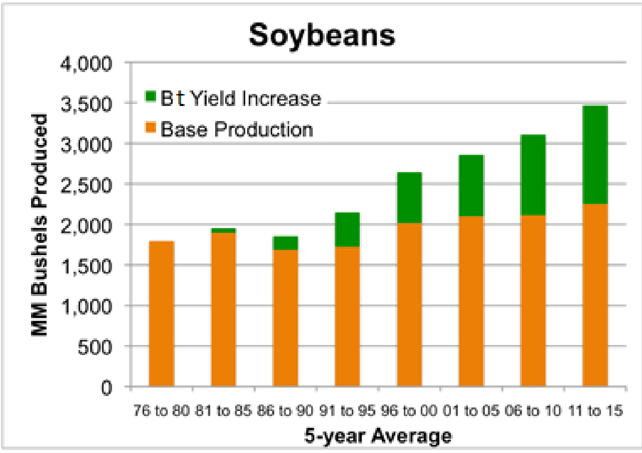

Figure 13. Increase in yield in GM soybean in USA.

Source: (Savage, 2016)

It is evident from the field performance of Bt brinjal that Bt technology is set to benefit farmers by mitigating economic losses and substantially increasing marketable yield, thus ensuring a bountiful harvest. For the first time, Bangladeshi consumers would have access to defect-free brinjal fruits. Previous experimental data indicate that Bt brinjal can improve yield by at least 30% and reduce the number of insecticide applications by a massive 70-90% resulting in a net economic benefit of US$1,868 per hectare. At the national level, Bt brinjal is estimated to have the capacity to generate a net additional economic benefit of US$200 million per year for around 150,000 brinjal growers in Bangladesh. Consumers will benefit from a cleaner, improved and more affordable food product (ISAAA, 2014)

4. Improvement in Nutritional Quality

Golden Rice expresses high levels of beta-carotene (a precursor of vitamin A) thanks to its modified genetic properties (Oliver, 2014). One bacterial gene and two daffodil genes were transferred into a variety of rice to develop a ß-carotene enriched strain. The main aim of the researchers was to help prevent vitamin A deficiency (VAD) which is a common phenomenon in developing countries. In 1995, clinical VAD affected some 14 million children under five, of whom some three million suffered xerophthalmia, the primary cause of childhood blindness. 250 million children had sub-clinical deficiency.

The figure 14 shows that even with a very little dietary intake of vitamin A from other sources (green), Golden rice varieties with a slight β-carotene content (orange) could fully provide the daily needs of the kids. Golden Rice lines with 4 µg/g β-carotene would be able to provide adequate levels of provitamin A in rice-based societies, especially when factoring in a modest contribution of provitamin A from other foodstuffs. A maintable supply of 50% RNI (red line) is able to hold adequate blood levels of vitamin A over time.

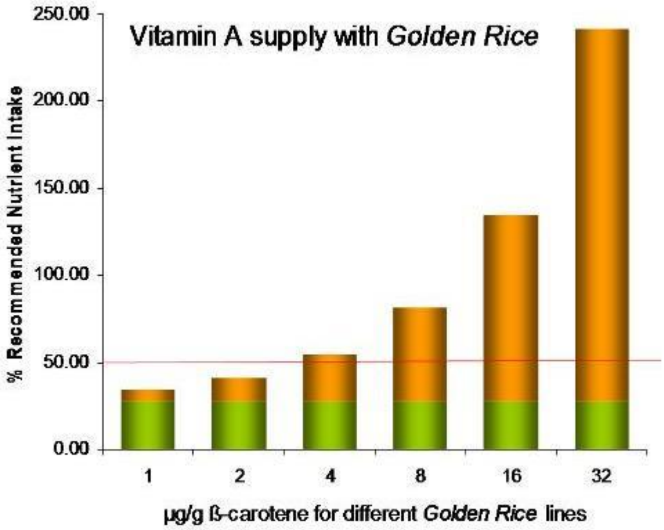

Figure 14. Capacity of Golden Rice lines with varying carotene content to supply the recommended nutrient intake of vitamin A

Source: (Mayer, 2018)

5. **Increase in Predator**

More recently, scientists reported a widespread and large increase in generalist predators (ladybirds, lacewings, and spiders) in China in association with the adoption of Bt cotton. That increase in generalist predators spilled over on to non-Bt crops (maize, peanut, and soybean) and resulted in enhanced biological control of aphid pests (Gilbert, 2013).

6. **Protection of the Environment**

The fuel savings associated with making fewer spray runs in GM IR (insect resistance) crops of maize, cotton and GM HT (herbicide tolarence) crops, have resulted in permanent savings in carbon dioxide emissions. In 2013, this amounted to a saving of about 2,096 million kg of carbon dioxide, arising from reduced fuel use of 785 million liters (Table 7). These savings are equivalent to taking 0.93 million cars off the road for one year.

Table 7: Carbon storage/sequestration from reduced fuel use with GM crops 2013

GM Crop	Country	Fuel saving (million liters)	Permanent carbon dioxide savings arising from reduced fuel use (million kg of carbon dioxide)	Permanent fuel savings: as average family car equivalents removed from the road for a year (‘000s)
GM HT soybean	Argentina	281	751	334
GM HR soybean	Brazil	171	456	203
GM HT maize	USA	79	211	94
GM HT canola	Canada	69	185	82
GM IR cotton	Global	13	34	15
IR maize	Brazil	30	80	36
Total		785	2,096	931

HT=Herbicide Tolerance, HR=Herbicide Resistance, IR=Insecticide Resistance

Source: (Brookes and Barfoot, 2015)

7. **Resistance against Abiotic Stresses**

Resistance to environmental stresses such as cold, moisture-stress and high salt levels in the soil can be attained in GM rice. In 2002, researchers at Cornell University successfully tested under greenhouse conditions a variety of GM rice that maintained yields under abiotic stresses such as cold, drought and salty soil. Such research is crucial since one third of the 1.5 billion hectares of the world’s arable land is affected by drought It is estimated that the modified variety has the potential to increase yields under poor conditions by as much as 20% (Thomas et al., 2003).

8. Resistance against Insects and Pests

Decades ago, a soil bacterium called *Bacillus thuringiensis* (Bt) was discovered that infects and kills the caterpillars that eat their crops. Already Bt crops have eliminated millions of gallons of pesticides, especially in cotton (Delude and Mirvis, 2000).

Bangladesh became the first nation to commercialize insect resistant Bt brinjal (eggplant) in 2013. Currently, there are about 6,000 farmers cultivating four varieties of the crop. Adoption has resulted in an 80%-90% reduction in insecticide use by the farmers who plant the crop. It is the country's first genetically modified crop that protects brinjal from the deadly fruit and shoot borer (FSB), which causes losses of up to 70% in commercial plantings. The four varieties popularly known as Bt Uttara, Bt Kazla, Bt Nayantara and Bt ISD-006 approved for commercial cultivation in four major brinjal growing regions: Gazipur, Jamalpur, Pabna and Rangpur.

Farmers' opinion of growing based on data collected and analyzed during the field demonstrations in 2014 and 2015 by BARI and DAE concluded that farmers' preference of growing because, farmers need not undertake sorting of infested/non-infested brinjal fruits as varieties were free from infestation of the fruit and shoot borer, the cost of production of was significantly lower due to almost no applications of insecticides for control of the fruit and shoot borer and, farmers obtained higher gross margin due to the bounty of additional fresh healthy brinjal fruits resulting in higher marketable fruits. Thus the adoption was increasing (Table 8).

Table 8: Adoption of Bt Brinjal in Bangladesh

Year	Adoption of Bt Brinjal (ha)	Total brinjal area (ha)	Num. of Bt Brinjal farmers
2014	12	50,000	120
2015	25	50,000	250
2016	700	50,000	2,500

Source: (Modified from; ISAAA, 2016)

The performance of Bt hybrids over non-Bt and popular hybrids of brinjal was examined in terms of yield gain and reduction in insecticide-use (Table 9). Overall, the quantities of insecticides used against FSB were reduced by 77.2 per cent, which amounted to 41.8 per cent reduction in the total insecticide-use in brinjal.

Table 9: Reduction in insecticide use and increase in fruit yield due to Bt brinjal hybrids

Year	Reduction in insecticide use* (%)		Increase in marketable fruit yield (%) over	
	Against FSB	Against all insect-pests	Hybrids used to develop Bt	Popular hybrids
2007-08	80.0	40.4	32.1	51.6
2008-09	74.5	43.2	45.2	58.9
Average	77.2	41.8	37.3	54.9

Note: *relates to the years 2004-05 and 2005-06

Source: (AICVIP, 2007)

The yield gain in Bt hybrids was 37.3 per cent over non-Bt hybrids and 54.9 per cent over popular hybrids. The incidence of shoot damage in Bt hybrids was very low, 0.24 per cent as compared to 4.64 per cent in check and 4.86 per cent in non-Bt hybrids (Kumar et al., 2011)

9. Resistance against Diseases

Since 1991 the Kenya Agricultural Research Institute (KARI), in cooperation with Monsanto and universities in the US, has developed GM sweet potato strains that are resistant to the feathery mottle virus. It is expected that yields will increase by approximately 18-25%. It has been predicted that the increased income will be between 28-39% (Thomas et al., 2003).

10. Resistance against Herbicides

As of 2015, GM herbicide resistance had been incorporated into soybean, maize, cotton, canola, sugar beet and alfalfa. Glyphosate-resistant weeds have now been found in 18 countries worldwide, with significant impacts in Brazil, Australia, Argentina and Paraguay (Gilbert, 2013). For example, in 2014, GM canola planting area (hectares) was up to 14% in 2014 from just 4% in 2009, representing a near three-fold increase and contributing to Australia's growing biotech crop hectarage (Zhang et al., 2016).

11. Economic Benefit

From 2006 to 2012, the global increase in farm income from GM food had reached $116 billion, almost triple that of previous 10 years. About 42% of the economic gain was from the increased yield due to advanced genetics and resistance to pests and weeds. The decreased costs of production (e.g. from reduced pesticide and herbicide usage) contributed the remaining 58% (Zhang et al., 2016). In a study, the production of GM crops indicates the gross farm income and it is cost saving (Table 10).

Table 10: Average gross farm income impacts 1996–2015 ($/hectare) for GM Crops

GM Crops	Cost of Technology	Avr. Gross farm income benefit(after deduction of cost of technology)	Aggregate income Benefit (million $)	Type of benefit
GM HT Maize	15-32	36.83	1,848.73	Cost savings
GM HT Cotton	31-78	76.28	252.71	Cost savings
GM HT Soybean	13-28	38	4,843	Cost savings
GM HT Sugarbeet	130–151	116	410.6	Mostly yield gains
GM HT Canola	11-35	53	1,826.33	Mostly yield gains

Source: (Brookes and Barfoot, 2017)

12. Ensuring Food Security

In a study, the average farm household owns 5 ha of land, without a significant difference between Bt adopters and non-adopters. Average annual per capita consumption expenditures range between 300 and 500 US$. Bt adopting households consume significantly more calories than non-adopting households, and a smaller proportion of them is food insecure (Table 11). The results inform that the cash income gains through Bt adoption may have enhance food security among cotton producing households.

Table 11: Descriptive statistics of farm households

Variables	Adopters of Bt (N= 1085)	Non-adopters of Bt (N= 346)
Farm size (ha)	5.11 (5.85)	4.85 (5.51)
Cotton area cultivated (ha)	2.35 (2.35)	2.79 (19.67)
Area cultivated with Bt cotton (ha)	1.97*** (2.08)	0.00 (0.00)
Age of farmer (years)	45.58 (12.86)	45.94 (12.36)
Education of farmer (years)	7.58*** (4.94)	6.69 (5.03)
Per capita consumption expenditure (US$/year)	490.31*** (430.18)	311.72 (355.58)
Off-farm income (US$/year)	560.70 (1455.44)	504.27 (2289.87)
Calorie consumption per AE (kcal/day)	3329.41*** (719.38)	2829.88 (598.99)
Calories consumed from more nutritious foods per AE (kcal/day)[a]	703.89*** (374.90)	638.89 (345.41)
Household size (AE)	5.01 (2.42)	5.14 (2.24)
Food insecure households (%)[b]	7.93***	19.94

N=Number of observations; AE=Adult equivalent. ***=Mean values between adopters and non-adopters of Bt are statistically significant at the 1% level. [a]=More nutritious foods include pulses, fruits, vegetables, and all animal products. [b]=Consumption of less than 2300 kcal per AE and day.

Source: (Qaim and Kouser, 2013)

If all non-adopters switched to Bt, the proportion of food insecure households would drop by 15–20% (Table 12).

Table 12: Impact of Bt adoption on food security among cotton-producing households

	Food insecure households (%)[a]	Change in food insecurity relative to status quo (%)
Non-adopters of Bt cotton (status quo)	19.94	
If non-adopters adopted Bt on their total cotton area	15.90	−20.26
If non-adopters adopted Bt on 85% of their cotton area	16.76	−15.95

[a]=Consumption of less than 2300 kcal per adult equivalent and day

Source: (Qaim and Kouser, 2013)

13. Improvement in Food Processing

The GM technology can also be employed to facilitate food processing. A notable achievement is "Flavr Savr" tomatoes. The genetic alteration consists of introduction of an antisense gene, which suppresses the enzyme polygalacturonase; the consequence is to slow down the ripening of tomatoes and thus allow longer shelf life for the fruits.

The transgenic fruit is containing levels of ethylene reduced by 85% relative to controls.

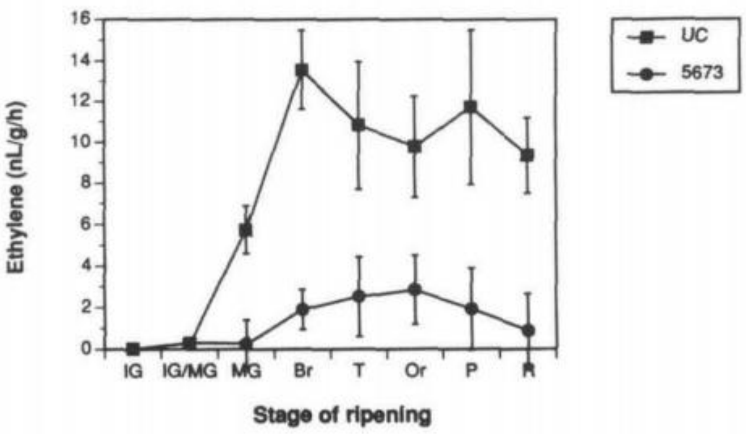

Figure 15. Ethylene production by GM and control fruit during ripening.

IG=Immature green; MG=mature green; Br=breaker; T=turning; Or=orange; P=pink; R=red

Source: (Klee, 1993)

14. Products for therapeutic purposes:

Genetic engineering techniques enable the expression of viral or bacterial antigens in the edible portion of plant cells. A variety of crops (e.g. rice, maize, soybean and potatoes) are under study as potential bearers of edible vaccines against different infections, including *Escherichia coli* toxins, rabies virus, *Helicobacter pylori* bacteria, and type B viral hepatitis (Zhang et al., 2016).

Table 13: The plant-based vaccines production for human and animal diseases

Diseases	Pathogens	Plants	Transformation method
Diarrheal	Norwalk virus	*Nicotiana benthamiana*	*Agrobacterium tumefaciens*
Tuberculosis	*Mycobacterium tuberculosis*	*Arabidopsis thaliana*	*Agrobacterium*
Avian H5N1 influenza	HA protein of H5N1	*Nicotiana benthamiana*	*Agrobacterium*
Dengue	Dengue virus type 2 E glycoprotein (EIII)	*Nicotiana tabacum* cv. MD609	*Agrobacterium tumefaciens*
Rabies	Rabies virus	*Nicotiana benthamiana*, tomato	Agroinfiltration
Hepatitis B	HBsAg	Tomato	*Agrobacterium tumefaciens*
Gaucher disease	Taliglucerase alfa	Carrot	Stable transformation
Nerve agents attack	Acetylcholinesterase	Tobacco	PEGylated
Diabetics	Insulin	Safflower	*Agrobacterium tumefaciens*
Human immunodeficiency	HIV	Tobacco	Agroinfiltration
Bluetongue	Bluetongue virus	*Nicotiana benthamiana*	Agroinfiltration
Ebola	Ebola virus	*Nicotiana benthamiana*	Agroinfiltration

HA=Hemagglutinin; HBsAg=Hepatitis B surface antigen

Source: (Laere et al., 2016)

15. Increase nitrogen use efficiency:

To improve the nitrogen use efficiency of plants, manipulation of several genes involved in nitrogen uptake, translocation, and remobilization; carbon metabolism; signalling targets; and regulatory elements are required. Several genes (Table 14) from different sources have been found to control these processes and were investigated if the manipulation of the genes can lead to improved nitrogen use of plants (Pathak et al., 2011).

Table 14. Genes studied for improvement of nitrogen use

Gene(s)	Source	Result(s)
Nif genes	*Klebsiella pneumoniae*	Activated nitrogenase function in *Escherichia coli*
GS1	Tobacco	Enhanced grain yield and biomass as well as improved nitrogen content in wheat, tobacco, and maize
AS1	*Arabidopsis*	Improved soluble seed protein content, total protein content, and better growth in nitrogen-limiting medium
Dof1	Maize	Improved growth under nitrogen limiting conditions as well as enhanced nitrogen assimilation
OsNADH-GOGAT1	Rice	Increase in spikelet weight of up to 80 percent in rice
STP13	*Arabidopsis*	Improved plant growth and nitrogen use

Source: (ISAAA, 2014)

Problems of Genetically Modified crops

1. **Food Safety**

People are concerned that GM foods could create new, unknown food allergies. Companies test the introduced gene for allergic properties and they must label a food if the gene comes from a known allergen such as nuts or wheat. Fungus and molds on foods cause health risks, and they are more common on organic crops. A mold that grows on corn and peanuts produces the cancer-causing chemical aflatoxin and can cause a whole crop to be rejected (Delude and Mirvis, 2000). Workers who applied Bt sprays also reported eye, nose, throat, and respiratory irritation.

2. **Health Risks**

GM crops are an "imperfect technology" with potential major health risks of toxicity, allergenicity and genetic hazards associated to them. These could be caused by inserted gene products and their potential pleiotropic effects, the GMO's natural gene disruption or a combination of both factors (Bawa and Anilakumar, 2013). The most notable example of this is Starlink maize, a Cry9c-expressing cultivar conferring gluphosinate resistance. In the mid-1990s, the USDA's Scientific Advisory Panel (SAP) classified Cry9c Starlink as "potentially allergenic" due to its potential to interact with the human immune system. In 2000, Starlink residues were detected in food supplies not only in USA but also EU, Japan and South Korea where it completely banned (Raman, 2017).

In a study, the stomach lining of rats fed GM potatoes showed excessive cell growth, a condition that may lead to cancer. Rats also had damaged organs and immune systems.

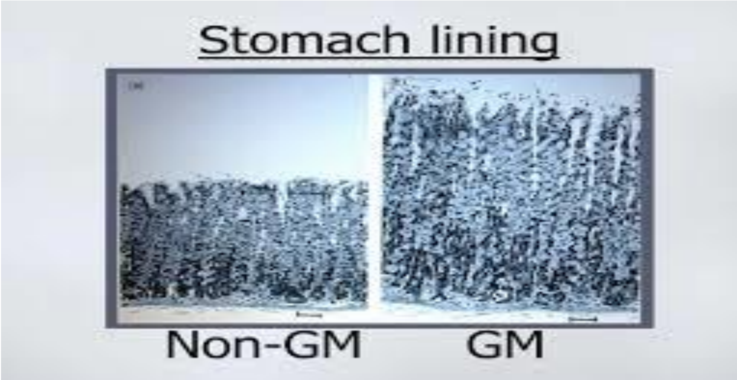

Figure 16. The stomach lining of rats fed GM potatoes.

Source: (Smith, 2015)

In other study, there were three feeding groups: the 'Control 1' given pellet food only, the 'Control 2' given non-GM soya in addition to pellet food, and the 'Experimental 1' group given GM soya in addition to pellet food (Table 15). Thirty-six percent of the pups from rats fed GM soya were severely stunted, some 5 to 6 times the percentage in the controls. By three weeks, 55.6 percent of the pups from rats fed GM soya had died, the death rate was 6 to 8 times the controls.

Table 15. Excess stunting and mortality in the progeny of rats fed GM soya

Feeding Groups	Num. of pregnant female	Pups	Pups dead at three weeks	Pups stunted at two weeks
Pellet	4	44	3 (6.8%)	6%
Pellet+Non GM soya	3	33	3 (9.1%)	6.7%
Pellet+GM soya	4	45	25 (55.6%)	36%

Source: (Ho, 2016)

3. Decrease in Biodiversity

According to the Center for Biological Diversity, the Monarch butterflies (*Danaus plexippus*) population has dropped 90 percent over the past 20 years. Every winter, Monarch butterflies migrate from the Midwestern United States corn-belt region to the Oyamel fir forests in Mexico. This chart from Monarch Watch which is a conservation group, shows the steep population change, in terms of the total area occupied by Monarchs during winter in Mexico.

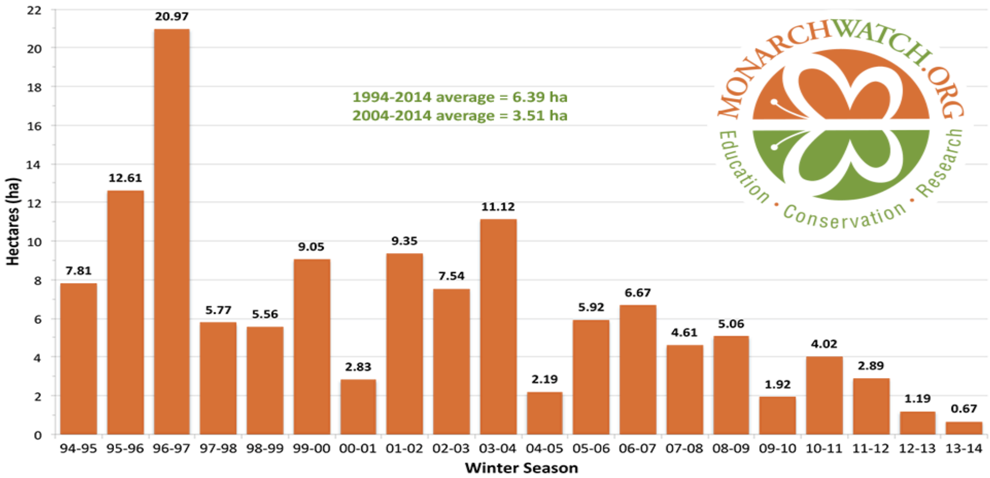

Figure17. Total area occupied by Monarch butterflies.

Source: (Carroll, 2015)

Recently, part of that habitat has been destroyed, and pesticide sprays throughout the migration path have further reduced the monarch's numbers. Some researchers planned a simple laboratory experiment to see what effect Bt maize had on monarch butterfly. They grew two types of corn: a "control" maize and a Bt variety. Then they dusted the maize pollen on the leaves of milkweeds. Scientists put these leaves in petri dishes with monarch caterpillars, which ate the pollen. The larvae that ate Bt pollen died within days,while the other larvae lived (Delude and Mirvis, 2000).

Duan et al. (2008) conducted a meta-analysis of 25 studies of Bt toxin effects on honey bee larvae and adults. They concluded that there was no evidence of any adverse effect on the honey bee. In a recent review of honey bee toxicology, Johnson (2015) concluded that evidence from many studies indicates that Bt pollen and nectar are not harmful to honey bees. At the individual farm level in the United States, there is little evidence of a substantial shift toward continous cropping (3 or more consecutive years of a single crop) of maize, soybean and wheat since the introduction of GE maize and soybean (Figure 18) (Wallander, 2013).

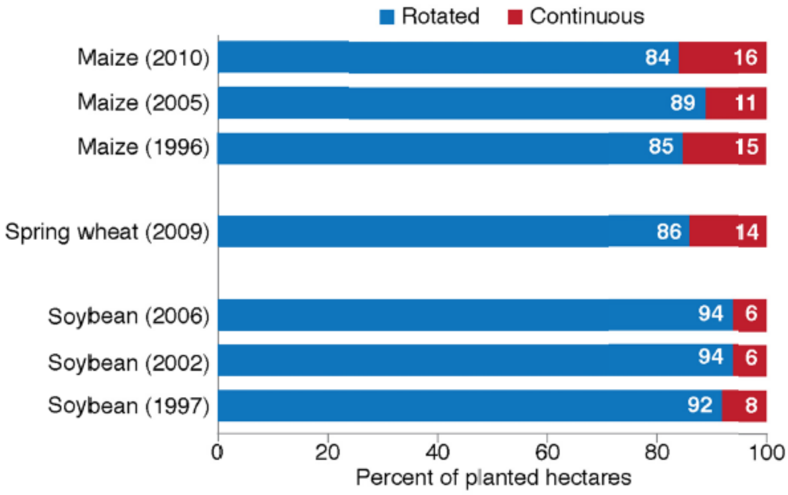

Figure 18: Percent of planted hectares under continous and rotational planting of maize,spring wheat and soybean in the United States,1997-2010.

Source: (Wallander, 2013)

4. Increase in Secondary Pests

The control of targeted species by Bt toxins sometimes provides an opportunity for increasing the populations of "secondary" insect species. The secondary insect pest populations increase because they are not susceptible to or have reduced susceptibility to the specific Bt trait in the crop. The insects would have been controlled by broad-spectrum insecticides that were used before the introduction of the Bt crop. One of the best examples of a secondary pest outbreak is in Bt cotton in China. In a 10-year study conducted from 1997 (when Bt cotton was introduced) through 2008, populations of a mirid bug (Heteroptera: Miridae), which is not affected by the Bt toxin in the cotton, steadily increased (National Academies of Sciences, Engineering, and Medicine, 2016).

Table 16 presents the findings from the farm surveys conducted in 2001 and 2004. The quantity of pesticide used to control secondary pests increased several fold in the 4 provinces.

Table 16: The average quantity (kg/ha) of pesticides used by farmers growing Bt cotton to control secondary pests in each province for 2001 and 2004

Surveys	2001	2004
1st survey	0.1	15.6
2nd survey	1.3	8.1
3rd survey	0.1	3.9
4th survey	5.1	8.7

Source: (Wang et al., 2008)

5. Rising of Superweed

It is very important whether herbicide-resistant crops will lead to "superweeds." Could the crops pollinate weeds and give them herbicide resistance? Would these resistant weeds spread out of control like the invasive kudzu vine in the south? Scientists began to study this possibility when herbicide-tolerant crops were developing through conventional crossbreeding. A herbicide-resistant crop can only pollinate a closely related weed. The Western Hemisphere has no wild relatives for soybeans, so herbicide-resistant weeds seem unlikely in this case. In the Eastern Hemisphere, the soybean does have weedy relatives that could get the herbicide-resistant gene. In the soybean field, farmers have to use other herbicides to kill the weeds, since it is only resist glyphosate. U.S. regulatory agencies are closely monitoring fields to make sure herbicide-resistant weeds are destroyed if they appear. **(**Delude and Mirvis, 2000)

6. Rising Costs

The increasing costs of seeds and inputs reflect the near-monopoly power of the biotech companies and indicate the growing market concentration in the wider agricultural input sector. Monsanto controls 98 per cent of the US seed market for soybean and 79 per cent of the maize market. The high cost of seeds is seen as a particular problem for small farmers, many of whom already struggle with debt. A study in Burkina Faso found that the cost was very high, so that the risks of GM cotton production became disproportionately high. Global Seed Sales total US$34,495 million in 2011 by the six multinational companies Monsanto, DuPont, Syngenta, Bayer, Dow, and BASF (Benbrook, 2012).

7. Suicide

After the introduction of genetically modified Bt cotton in 2002, a rise in suicide rates among Indian farmers was found.

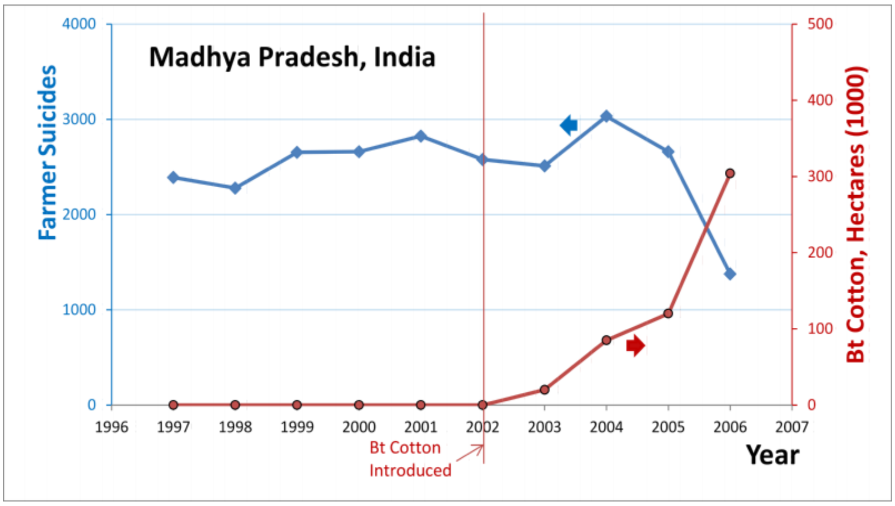

Figure 19. Bt cotton and farmers suicide.

Source: (Hunter, 2014)

Precaution and Regulation

Most people agree that an assessment of the environmental safety of GM crops should focus primarily on the severity of the consequences of gene flow. However, some also take the view that GM crops should not be developed at all because there may be a very low probability that some unpredictable and serious adverse consequences may ensue. This case is frequently argued in terms of the so called precautionary approach. The argument is that, irrespective of possible benefits, a new technology should never be introduced unless there is a guarantee that no risk will arise (Thomas et al., 2003).

GM crops were regulated from the beginning, and these regulations were strengthened in 2000. The Environmental Protection Agency (EPA) requires permits and testing for pest- and herbicide-resistant crops and is researching the potential problem of superweeds and superbugs. Companies must submit detailed safety information to the Food and Drug Administration (FDA) before introducing a new GM food. The U.S. Department of Agriculture (USDA) oversees field tests of GM crops (Delude and Mirvis, 2000).

To mitigate the problems regarding GM technologies, a series of strict regulatory measures have been proposed to prevent cross-contamination of split-approved GM crops banned for human consumption. These include implementation and enforcement buffer zones to prevent cross contamination of crops, better laboratory testing to confirm adverse allergic event cases and an overall inclusion of stakeholders and representatives in policymaking and communication (Raman, 2017).

Future Hope

Most varieties of *Lathyrus sativus*, a lentil formerly grown widely in North India and now spreading in Ethiopia, are known to cause the crippling disease of lathyrism. Traditional varieties of cassava in Nigeria also have dangerously high levels of hydrocyanic acid. Research on GM crops could create safer varieties of these and other crops which could replace harmful traditional varieties by reducing the levels of undesirable substances including mycotoxins, alkaloids and glucosinolates.54 Approaches to avoid resistance might be to use two or more *Bt* genes,48 or to carry out research into new insecticidal genes that could eventually take the place of *Bt*.49 However, at present *Bt* varieties have remained resistant to pest infestation for considerably longer than had initially been anticipated (Thomas et al., 2003).

To offer farmers new weed-control strategies, Monsanto and other biotechnology companies, such as Dow AgroSciences, based in Indianapolis, Indiana, are developing new herbicide-resistant crops that work with different chemicals, which they expect to commercialize within a few years (Gilbert, 2013). More progress in crop improvement could be made by using conventional breeding and genetic engineering jointly rather than in isolation (Zhang et al., 2016).

CHAPTER IV

CONCLUSIONS

- Traditional agricultural methods involve modification of genes of plants to develop desirable traits. In contrast, DNA recombination leads to highly targeted transfer of genes from almost any organism to produce the genetically modified crops. Genetically modified (GM) crops can mitigate several current challenges in modern agriculture. To meet the demands of population growth, improved nutritional standards and decreasing arability, GM crops play a vital role. The production of GM crops is in 175 million hectares worldwide whereas soybean, maize, cotton and canola occupy 99% of the GM crop production, while Bangladesh produce only Bt brinjal on 700 hectares land.
- Current market trends project GM crops as one of the fastest growing and innovative global industries, which not only benefit growers but also consumers and major country economies. The GM crops solve many of the world's hunger and malnutrition problems, and to help protect and preserve the environment by increasing yield and reducing reliance upon synthetic pesticides and herbicides, while also grow under abiotic and biotic stresses thus achieve sustainable global food security.
- Having numerous benefits, GM crops have many problems related to healh and biodiversity. Imperfections and major GM technology can also be combated by stricter regulation, monitoring and implementation by government agriculture bodies, a globally improved risk mitigation strategy and communication with growers, therefore ensuring greater acceptance. The risks should have been tested and eliminated before their introduction. Considerable effort need to be directed towards understanding people's attitudes towards this gene technology. With key innovation in precision gene-integration technologies and emerging research in biofortification and stress tolerance, GM crops are forecast to bring productivity and profitability in modern agriculture for smoother progress in the future**.**

REFERENCE

AICVIP (All India Co-ordinated Vegetable Improvement Project). (2007). Performance of Multi-location Research Trials of Bt Brinjal Hybrids, *Indian Institute of Vegetable Research (Indian Council of Agricultural Research), Varanasi*.

Alexandratos, N., & Bruinsma, J. (2012). World agriculture towards 2030/2050. *FAO, Rome: ESA Working paper. 12*(3).

Atici, C. (2014). Low levels of genetically modified crops in international food and feed trade: FAO international survey and economic analysis. *FAO Commodity and Trade Policy Research Working Papers*, *44*: 0-1.

Bawa, A. S., & Anilakumar, K. R. (2013). Genetically modified foods: safety, risks and public concerns—a review. *Journal of Food Science and Technology*, *50*(6): 1035-1046.

Benbrook, C. M. (2012). Impacts of genetically engineered crops on pesticide use in the US-the first sixteen years. *Environmental Sciences Europe*, *24*(1).

Brookes, G., & Barfoot, P. (2015). Environmental impacts of genetically modified (GM) crop use 1996–2013: Impacts on pesticide use and carbon emissions. *GM Crops & Food*, *6*(2): 103-133.

Brookes, G., & Barfoot, P. (2017). Farm income and production impacts of using GM crop technology 1996–2015. *GM Crops & Food*, *8*(3): 156-193.

Carroll, L. (2015). Are GMOs causing monarch butterflies to become extinct? *http://www.politifact.com/truth-statements/2015/feb/17/peter-defazio/are-gmos-causing-monarch-butterflies-become-extinct/*

Cohen, S. N., Chang, A. C., Boyer, H. W., & Helling, R. B. (1973). Construction of biologically functional bacterial plasmids in vitro. *Proceedings of the National Academy of Sciences*, *70*(11): 3240-3244.

Delude, C. M., & Mirvis, K. W. (2000). Your world: Biotecnology & You, *A magazine of biotechnology applications in healthcare, agriculture, the environment and industry, The Biotechnology Institute*, 10(1).

Duan, J. J., Marvier, M., Huesing, J., Dively, G., & Huang, Z. Y. (2008). A meta-analysis of effects of Bt crops on honey bees (Hymenoptera: Apidae). *PLos One*, *3*(1): e1415.

FAO, (2016). The State of Food Insecurity in the World 2015. *Food and Agriculture Organization Publications, Rome*.

Fernandez-Cornejo, J., Wechsler, S., Livingston, M., & Mitchell, L. (2014). Genetically engineered crops in the United States.

Fleischer, Shelby, J., Hutchison, William, D., Naranjo, Steven, E. (2014). Plant Biotechnology. *Springer International Publishing*. 115–127.

Gilbert, N. (2013). A hard look at GM crops. *Nature*, *497*(7447): 24.

Green, J. M. (2014). Current state of herbicides in herbicide-resistant crops. *Pest Management Science*, *70*(9): 1351-1357.

Ho, M. W. (2016). GM soya fed rats: stunted, dead or sterile. *Science in Society, 33*: 4-6.

Hunter, M. T. (2014). Bt Cotton Hectares and Farmer Suicides Time Trend.

ISAAA (International Service for the Acquisition of Agri-biotech Applications). (2014). Executive Summary: The status of Commercialized Bt Brinjal. Brief 47. ISAAA.org. *www.isaaa.org*

ISAAA (International Service for the Acquisition of Agri-biotech Applications). (2014). Nitrogen Use Efficient Biotech Crops. ISAAA.org. *www.isaaa.org*

ISAAA (International Service for the Acquisition of Agri-biotech Applications). (2016). GM Crops List | GM Approval Database- ISAAA.org. *www.isaaa.org.*

James, C. (2002). Global Review of Commercialized Transgenic Crops: 2001, Feature Bt cotton. ISAAA Brief No. 26.

James, C. (2014). Global status of commercialized biotech/GM crops: 2013, ISAAA Brief No. 46*. International Service for the Acquisition of Agri-Biotech Applications, Ithaca, NY*. ISBN 978-1-892456-55-9.

Johnson, R. M. (2015). Honey bee toxicology. *Annual Review of Entomology*, *60*.

Klee, H. J. (1993). Ripening physiology of fruit from transgenic tomato (*Lycopersicon esculentum*) plants with reduced ethylene synthesis. *Plant Physiology*, *102*(3): 911-916.

Klumper, W., & Qaim, M. (2014). A meta-analysis of the impacts of genetically modified crops. *Plos one*, *9*(11): e111629.

Kumar, S., Prasanna, P. A., & Wankhade, S. (2011). Potential Benefits of Bt Brinjal in India-An Economic Assessment. *Agricultural Economics Research Review*, *24*(1).

Laere, E., Ling, A. P. K., Wong, Y. P., Koh, R. Y., Lila, M., Azmi, M., & Hussein, S. (2016). Plant-based vaccines: Production and challenges. *Journal of Botany*. ID 4928637.

Lin, C. H., & Pan, T. M. (2016). Perspectives on genetically modified crops and food detection. *Journal of Food and Drug Analysis*, *24*(1): 1-8.

Mayer, J. (2018). Vitamin A Deficiency-Related Disorders (VADD).

McCarty, M., & Avery, O. T. (1946). Studies on the Chemical Nature of the Substance Inducing Transformation of Pneumococcal Types: iii. An Improved Method for the Isolation of the Transforming Substance and Its Application to Pneumococcus Types ii, iii, and Vi. *Journal of Experimental Medicine*, *83*(2): 97-104.

National Academies of Sciences, Engineering, and Medicine. (2016). Genetically engineered crops: experiences and prospects. *National Academies Press*.

National Research Council. (2010). The impact of genetically engineered crops on farm sustainability in the United States. *National Academies Press*.

Newell-McGloughlin, M. (2008). Nutritionally improved agricultural crops. *Plant Physiology*, *147*(3): 939-953.

Nirenberg, M. W., Matthaei, J. H., Jones, O. W., Martin, R. G., & Barondes, S. H. (1963, January). Approximation of genetic code via cell-free protein synthesis directed by template RNA. *Federation Proceedings. 22*: 55-61.

Oliver, M. J. (2014). Why we need GMO crops in agriculture. *Missouri medicine*, *111(*6): 493.

Pathak, R. R., Lochab, S. & Raghuram, N. (2011). Improving Plant Nitrogen-Use Efficiency. Comprehensive Biotechnology, Second Edition, *Elsevier*. *4*: 209-218.

Perry, E. D., Ciliberto, F., Hennessy, D. A., & Moschini, G. (2016). Genetically engineered crops and pesticide use in US maize and soybeans. *Science Advances*, *2*(8): e1600850.

Phillips, T. (2008). Genetically modified organisms (GMOs): Transgenic crops and recombinant DNA technology. *Nature Education, 1*(1): 213.

Pispini, M., Schimpf, M., Lopez, J. & Chandrasekaran, K. (2014). Who Benefits From GM Crops? *Friends of the Earth International*

Qaim, M., & Kouser, S. (2013). Genetically modified crops and food security. *Plos One*, *8*(6): e64879.

Qaim, M., & Zilberman, D. (2003). Yield effects of genetically modified crops in developing countries. *Science*, *299*(5608): 900-902.

Raman, R. (2017). The impact of Genetically Modified (GM) crops in modern agriculture: a review. *GM crops & Food*. *8*(4): 195-208

Ray, D. K., Mueller, N. D., West, P. C., & Foley, J. A. (2013). Yield trends are insufficient to double global crop production by 2050. *Plos one*, *8*(6): e66428.

Smith, J. M. (2015). Genetic Roulette: The Documented Health Risk of Genetically Engineered Foods, *Institute for Responsible Technology*.

Stein, A. J., & Rodríguez-Cerezo, E. (2010). Low-level presence of new GM crops: an issue on the rise for countries where they lack approval. *Agrobioforum. 13*(2): 173-182

The Royal Society. (2018). What is genetic modification (GM) of crops and how is it done?

Thomas, S., Burke, D., Gale, M., Lipton, M., & Weale, A. (2003). The use of genetically modified crops in developing countries. *A follow-up Discussion Paper, Nuffield Council on Bioethics*

Us census Bureau, international database, 2016

Wallander, S. (2013). Soil Tillage and Crop Rotation. *USDA Economic Research Service*.

Wang, S., Just, D. R., & Pinstrup-Andersen, P. (2008). Bt-cotton and secondary pests. *International Journal of Biotechnology*, *10*(2-3): 113-121.

Wikipedia, the free encyclopedia. (2018). List of genetically modified crops.

World Health Organization, (2016). *http://wwww/foodsafety/areaswork/food-technology/genetically-modified-food.*

Zhang, C., Wohlhueter, R., & Zhang, H. (2016). Genetically modified foods: A critical review of their promise and problems. *Food Science and Human Wellness*, *5*(3): 116-123.