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Review Article

The Impact of Genetically Modified Crops in the Present Scenario

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Abstract

Genetic modification in plants was first recorded 10,000 years ago in Southwest Asia. Genetically modified (GM) crops represent the most rapidly adopted technology in the history of agriculture, having now reached 25 years of commercial production. This technology has led to the commercial production of genetically engineered (GE) crops on approximately 250 million acres worldwide. Genetically modified (GM) crops have generated a great deal of controversy as its benefits for both food producers and consumers are companied by potential biomedical risks and environmental side effects. By means of genetic engineering, genes can be introduced into the same plant or animal species for the improvement of their beneficial qualities. These crops contain desired genes that make them pest resistant and insect resistant, and also in other GM crops, genetic engineers improved their nutrient quality and storage life-time by the insertion of desired genes. Agronomic traits engineered to meet the need for an expanding global population will help us produce more food on the same amount of arable land. Quality trait engineering will help to alleviate nutritional deficiencies in populations with limited food selection. Increasing concerns from the public about GMO, particularly in the form of genetic modified (GM) foods, are aimed at the short- and long- lasting health problems that may result from this advanced biotechnology.

Economic impact studies currently dominate the literature and mainly report that GM crops provide economic benefits for farmers. Other social impacts are less well studied, but present a more complex picture. At a global level in different countries, private and government organizations support food biotechnology as a means to avoid global food shortage. Many new policy rules are being made by the government to balance support of the food biotechnology industry with public calls for their regulation. Such regulation help to improve to protect public health and safety, to promote international trade, conserve the natural resource, and account for ethical issue. In this review, Genetic Engineering process, its need in the agricultural system, status and safety of GM crops, their applications and negative impacts on the environment will be addressed. Also, nutritional enhancement, importance of GMOs and social and economic impacts of GM feed crops in the agricultural system; trends, productivity and price controls will be covered in this review.

Introduction

The human population has grown at a breakneck pace and threatens to further exacerbate a problem that has worsened in recent years: chronic hunger. Genetically modified crops could help to relieve this problem by providing increased yields and being more resistant to environmental stressors. In particular, the increasing prevalence of drought has prompted the development of crops that are more tolerant of high temperatures. Regardless, continuing to research this type of genetic engineering remains a promising strategy for feeding the world's growing population [1]. Genetic modification (GM) is the area of biotechnology which concerns itself with the manipulation of the genetic material in living organisms, enabling them to perform specific functions [2].

Genetically Modified Organism is defined by WHO as "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" [3]. Genetically modified crops (GM crops) are plants used in agriculture, the DNA of which has been modified using genetic engineering methods. Plant genomes can be engineered by physical methods or by use of Agrobacterium for the delivery of sequences hosted in T-DNA binary vectors. There is a scientific consensus that currently available food derived from GM crops poses no greater risk to human health than conventional food, but that each GM food needs to be tested on a case-by-case basis before introduction. Nonetheless, members of the public are much less likely than scientists to perceive GM foods as safe.

History

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 [4]. In agriculture, the first GM plants – antibiotic resistant tobacco and petunia – were successfully created in 1983 by three independent research groups. In 1994, the Flavr Savr tomato (Calgene, USA) became the first ever Food and Drug Administration (FDA) approved GM plant for human consumption. Since then, several transgenic crops received approvals for large scale human production in 1995 and 1996 [2]. With the creation of golden rice in 2000, scientists had genetically modified food to increase its nutrient value for the first time. Bt cotton was the first genetically modified crop to be approved for cultivation in India in 2002, with the introduction of Monsanto's GM cotton seeds.

Examples of Genetically Modified Crops in India

Initial FDA-approved plants included corn/maize, cotton and potatoes (*Bacillus thuringiensis* (Bt) gene modification, Ciba-Geigy and Monsanto) canola (Calgene: increased oil production), cotton (Calgene: bromoxynil resistance) and Roundup Ready soybeans (Monsanto: glyphosate resistance). Currently, the GM crop pipeline has expanded to cover other fruits, vegetables and cereals such as lettuce, strawberries, eggplant, sugarcane, rice, wheat, carrots etc.

Golden Rice

Golden rice is the collective name of rice varieties that are genetically modified to counter vitamin A deficiency in developing countries. Golden rice is a variety of rice (*Oryza sativa*) produced through genetic engineering to biosynthesize beta-carotene, a precursor of vitamin A, in the edible parts of rice. European scientists developed the first strain of Golden Rice towards the end of the 1990s. Golden rice differs from standard rice in that it contains extra genes. These were added through genetic modification and ensure the production of provitamin A in the rice grains. Provitamin A colors the grains yellow-orange, hence the name 'Golden Rice'. Once absorbed into the body, provitamin A is converted into vitamin A [5].

Bt Cotton

For the time being, the only genetically modified crop that is under cultivation in India is bt cotton which is grown over 10.8 million hectares. Bt cotton was first used in India in 2002 [6]. Bt cotton-incorporating genes from the *Bacillus thuringiensis* or Bt soil bacterium coding for resistance against heliothis bollworm insect pests [5].

Bt Brinjal

The GEAC in 2007 recommended the commercial release of BT brinjal, which was developed by Mahyco (Maharashtra hybrid Seeds Company) in collaboration with the Dharward University of Agricultural Sciences and the Tamil Nadu Agricultural University. But the initiative was blocked in 2010 [6].

GM Mustard

Dhara Mustard Hybrid-11 or Dmh-11 is a genetically modified variety of mustard developed by the Delhi University's Centre for Genetic Manipulation of Crop Plants. The researchers at Delhi University have created hybridized mustard dmh-11 using "barnase / barstar" technology for genetic modification. It is Herbicide Tolerant (Ht) Crop. If approved by the Centre, this will be the second GM crop, after BT cotton, and the first transgenic food crop to be allowed for cultivation in the country [6].

Genetic Engineering in the Agricultural System

New genome technologies along with bioinformatics will further propel Indian agriculture into a new era where complex traits such as photosynthetic efficiency and crop yield can be enhanced. Genomic tools with esoteric names such as 'DNA chips', 'Gene Shuffling' and 'Directed Evolution' Allele mining, CRISPER/cas9, RNA interference technology, Nanopore sequencing are a milestone for agricultural research. There are following aspects of genetic engineering in agriculture system [7].

Genetically Engineered Plants: Many genetically engineered plants have been commercialized in agriculture, including tomatoes and squash and commodity crops like corn canola, cotton, and soybeans. Most have been engineered for one of three traits: herbicide tolerance, insect resistance, or virus tolerance. The most cultivated transgenic crop is herbicide-tolerant maize.

Genetically Engineered Fiber Plants: Genetically engineered cotton has been approved for commercial use known as bt cotton. The use of bt cotton in India has grown exponentially since its introduction in 2002.

Abiotic Stress Tolerance Engineered plant: With no more arable land available for agricultural expansion in India, enhancing stress tolerance in crop plants will permit productive farming on currently unproductive lands. Abiotic factors such as drought, heat, cold, soil salinity and acidity cripple Indian crops seriously constraining their growth and yield. One could extend the growing season of crops and minimize losses due to environmental factors. The shelf life of fruits and vegetables can be prolonged to reduce losses due to food spoilage, expand the market vista and improve food quality. In India recently developed Salt tolerance rice.

Bio-Fertilizers

Certain micro-organisms and minute plants that can absorb gaseous nitrogen and phosphorous directly from the atmosphere and make it available to the plants can be identified, multiplied in the laboratories and introduced into the root zone of crop plants to supply nitrogen and phosphorous. Materials containing such organisms are called biofertilizers. Some of the biofertilizers are Rhizobium, Azotobacter, Azispirillium, Blue- green algae, Azolla, etc. [7].

Need for Agriculture Biotechnology in India

The strategic integration of biotechnology tools into Indian agricultural systems can revolutionize Indian fanning and usher in a new era in the countryside. Compared to the “green revolution”, the “gene revolution” relatively scales neutral, farmers alike. It is also environment-friendly. Thus, it can be of great help to the smallest farmer with limited resources, in increasing farm productivity through the availability of’ improved but powerful seed. It can also reduce his dependency on chemical inputs such as pesticides and fertilizer [7].

Status of GM Crops in India

India is both the world’s largest cotton producer and largest Bt cotton producer with an adoption rate of 95% for Bt cotton [8]. In 2001, thousands of small-scale Indian farmers were discovered to be illegally planting Bt cotton, before government approval followed in 2002, a typical bottom-up16 development of the law. Although cultivation approval exists for non-food GM cotton, a de facto moratorium endures for the GM food crop, Bt brinjal. The only approved GM crop in India till date is Bt. Cotton. For developing resistance to Lepidoptera order of insects such as butterflies and moths, a gene from *Bacillus thuringiensis* var. kurstaki bacteria is introduced, which produces a protein insecticidal to Lepidoptera larvae, thereby aiding cotton production without excessive use of chemical insecticides. Likewise, there are GM varieties for crops like Maize, Soyabean, Brinjal, etc. around the world. However, different regulations exist in different parts of the globe for cultivation of GM crops. One hundred and seventy two countries, including India, have signed the Cartagena Protocol on Biosafety, an international agreement to ensure safe handling, transport and use of living modified organisms which are a result of modern biotechnology [9] Figure 1.

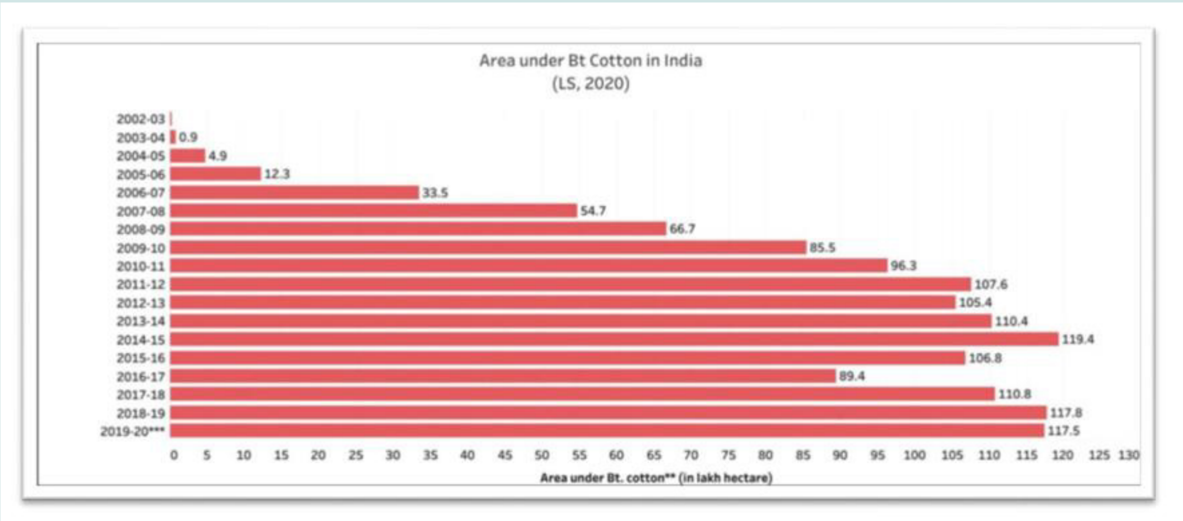

Figure 1: Status of GM Crops Globally.

Objectives of the Genetically Modified Crops in Modern Agriculture

a) The GM crops has been increased in production 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 [2].

b) In most cases, the aim is to introduce a new trait to the plant which does not occur naturally in the species.

c) One of the objectives for developing plants based on GM organisms is to improve crop protection. The GM crops currently on the market are mainly aimed at an increased level of crop protection through the introduction of resistance against plant diseases caused by insects or viruses or through increased tolerance towards herbicides that help farmers control weeds without damaging the crops [3].

d) The most common GMO crops were developed to address the needs of farmers, but in turn they can help foods become more accessible and affordable for consumers. Some GMO crops were developed specifically to benefit consumers. For example, a GMO soybean that is used to create healthier oil is commercially grown and available. GMO apples that do not brown when cut are now available for sale and may help reduce food waste. Plant scientists continue to develop GMO crops that they hope will benefit consumers [10].

e) Genetic engineering is used to improve staple crops, the basic foods that make up a large portion of people's diets. For example, a GMO eggplant developed to be insect resistant has been slowly released to farmers in Bangladesh since 2014. Farmers who grow GMO eggplants are earning more and have less exposure to pesticides [10].

f) GM crops have been recorded to reduce environmental and ecological impacts, leading to increases in species diversity [2].

g) Another reason for opting for genetically engineered foods is that they have an increased shelf life and hence there is less fear of foods getting spoiled quickly [11].

h) Genetically engineered foods are reported to be high in nutrients and contain more minerals and vitamins than those found in traditionally grown foods [11].

Problems Associated with the Genetically Modified Foods

a) The biggest threat caused by GM foods is that they can have harmful effects on the human body. It is believed that consumption of these genetically engineered foods can cause the development of diseases which are immune to antibiotics [11].

b) This cross-pollination method can cause damage to other organisms that thrive in the environment [11].

c) GMO foods are that they may cause allergic reactions because of their altered DNA and they may increase antibiotic resistance [12].

d) Faster growth of GMOs can enable them to have a competitive advantage over the native organisms. This may allow them to become invasive, to spread into new habitats, and cause ecological and economic damage [13].

e) The effects of changes in a single species may extend well beyond to the ecosystem. Single impacts are always joined by the risk of ecosystem damage and destruction [13].

f) One risk of particular concern relating to GMOs is the risk of horizontal gene transfer (HGT). HGT is the acquisition of foreign genes (via transformation, transduction, and conjugation) by organisms in a variety of environmental situations. It occurs especially in response to changing environments and provides organisms, especially prokaryotes, with access to genes other than those that can be inherited. HGT of an introduced gene from a GMO may confer a novel trait in another organism, which could be a source of potential harm to the health of people or the environment. For example, the transfer of antibiotic resistance genes to a pathogen has the potential to compromise human or animal therapy [13].

g) Regulatory approvals for field trials of GMOs often require measures to limit and control the release in space and time. With the spread of the introduced gene(s) to another species by HGT, a new GMO is created. This new GMO may give rise to adverse effects which are not controlled by management measures imposed by the original license or permit [13].

h) Sometimes the impact of HGT may be more severe in the long term. Even under relatively strong selection pressure, it may take thousands of generations for a recipient organism to become the dominant form in the population [13].

i) Eating GMO foods can contribute to the development of cancer, because the disease is caused by mutations in DNA, it is dangerous to introduce new genes into the body [14].

j) Outcrossing refers to the risk of genes from certain GMO plants mixing with those of conventional crops. There have been reports of low levels of GMO crops approved as animal feed or for industrial use being found in food meant for human consumption [14].

Potential Applications of GM Crop Technology of the Future

Nutritional enhancement: Higher vitamin content; more healthful fatty acid profiles;

Stress tolerance: Tolerance to high and low temperatures, salinity, and drought;

Disease resistance: For example, orange trees resistant to citrus greening disease or American chestnut trees resistant to fungal blight;

Biofuels: Plants with altered cell wall composition for more efficient conversion to ethanol;

Phytoremediation: Plants that extract and concentrate contaminants like heavy metals from polluted sites [15].

Steps of Making GM Crops

Identify: To produce a GMO plant, scientists first identify what trait they want that plant to have, such as resistance to drought, herbicides, or insects. Then, they find an organism (plant, animal, or microorganism) that already has that trait within its genes. In this example, scientists wanted to create insect-resistant corn to reduce the need to spray pesticides. They identified a gene in a soil bacterium called *Bacillus thuringiensis* (Bt), which produces a natural insecticide that has been in use for many years in traditional and organic agriculture.

Copy: After scientists find the gene with the desired trait, they copy that gene. For Bt corn, they copied the gene in Bt that would provide the insect-resistance trait.

Insert: Next, scientists use tools to insert the gene into the DNA of the plant. By inserting the Bt gene into the DNA of the corn plant, scientists gave it the insect resistance trait.

This new trait does not change the other existing traits.

Grow: In the laboratory, scientists grow the new corn plant to ensure it has adopted the desired trait (insect resistance). If successful, scientists first grow and monitor the new corn plant (now called Bt corn because it contains a gene from Bacillus thuringiensis) in greenhouses and then in small field tests before moving it into larger field tests. GMO plants go through in-depth review and tests before they are ready to be sold to farmers.

Nutritionally- Enhanced GM Feed Crops

Genetic modification using recombinant DNA techniques, termed as metabolic engineering, is being conducted to generate new varieties with high yielding and nutrition-enhanced traits. Nutrition enhancement in crops targets manipulation of levels of proteins and amino acids, fats and oils, vitamins and minerals, carbohydrates and fiber quality, as well as decreasing the levels of undesirable components in major feed crops [8].

Feed Crops with Improved Proteins and Amino Acids

For animal requirement, most grains do not provide a balanced source of protein due to deficiencies in essential amino acids: lysine, methionine, and tryptophan. Biotechnology has been successfully utilized in the development of crops with increased level of limiting amino acids, thus providing alternative to the direct addition of supplemental amino acids in animal diets, as well as reducing N excretion into the environment. GM maize with increased lysine (LY038) was developed by inserting a *cordapA* gene from a common soil bacteria *Corynobacterium glutamicum*. Enhanced production and accumulation of free lysine (Lys) in the GM corn kernel made body weight gain, feed conversion and carcass yields of experimental poultry and swine comparable with animals fed with Lys supplemented diets, and higher than those fed with conventional maize diets [16]. Rats fed with another Lys-enriched maize with the gene sourced from potato, was also found to be safe as conventional maize [17]. Protein-enriched soybean event M703 was found to contain more digestible amino acids lysine, methionine, threonine, and valine, and had a higher level of metabolizable energy than conventional soybean meal in an experiment with cockerels [18].

Feed Crops with Improved Phosphorus Availability

The element phosphorus (P) is stored in plants as phytate salt. When consumed by monogastric animals such as horse, pig, poultry, cat, dog, among others, it is poorly soluble and utilized in the gastrointestinal tract, when accompanied with high dietary calcium concentration and absence of endogenous phytase (enzyme hydrolyzing phytate bonds that releases elemental P) activity. Hence, the undigested phosphates excreted by these animals when accumulated in soil and water leads to phosphorous pollution and organic matter accumulation, eventually reducing oxygen availability in the water [19]. In addition, phytic acid (the reactive form of phytate salt) forms insoluble salts with zinc and other cations reducing bioavailability of trace minerals in these animals. Thus, development of GM crops with phytase enzyme is an important solution to this problem.

GM corn expressing the *Escherichia coli*-derived phytase gene when studied with broiler chicks showed that the use of an increasing dietary level of transgenic maize linearly increased dry matter P, calcium (Ca) and nitrogen (N) retention. It shows that the GM corn is as efficacious as the commercial, microbial phytase in P- and Ca-deficient broiler diets and would thus minimize the need for supplemental dietary P [20]. Genetically modified soybean that express *Aspergillus niger* phytase transgene was tested in broiler chicks in comparison with phytase-supplemented commercial feed [21]. On the basis of performance, P retention and excretion, the authors indicated that phytase from GM soybeans gave a positive effect, similar to the one provided by commercial phytase supplement. Tobacco and wheat containing the same gene showed similar beneficial influence on P availability in broiler chicks [22]. Use of GM canola with phytase gene from *Aspergillus fucuum* in broiler chicks and weaning pigs also showed that bone ash, P and Ca retention were comparable with that of feeds containing commercial phytase supplement [23].

Developing Feed Crops with Improved Fatty Acids

Most of the GM crops modified to improve fatty acid content have been used for direct food or for food industry use such as the oleic acid soybean DP305423, which has a better oxidative ability for improved food frying performance. Safety and nutritional value of the processed meal, hulls and oils from the GM soybean plant determined from experiments in birds showed that it is nutritionally equivalent to non-modified control as shown in body weight, hen-day egg production, egg mass, feed intake as well as egg production and quality [24].

Feed Crops with Reduced Toxins and Anti-nutritive Factors

Non-ruminants are adversely affected by anti-nutritive factors in plant tissues including protease inhibitors, tannins, phytohaemogglutinins and cyanogens in legumes, and glucosinolates, tannins and sanapine in oilseed and other compounds in feeds belonging to the Brassica group. A combination of genetic engineering and conventional plant breeding should lead to substantial reduction or removal of the major anti nutritive factors in plant species of importance to animal feeds. Soybeans contain raffinose and stachyose, the antinutritive oligosacharides that cause osmotic problems in laboratory animals. Genetically modified soybeans that contain these low oligosaccharides were developed. In an experiment with three conventional soybean meals and five low-oligosaccharide GM soybean meals fed to broilers, the mean raffinose, stachyose, and galactinol levels in the GM soybean was significantly much lower than the conventional soybean meal, and the crude protein and sucrose contents were slightly higher. Additional data showed that true metabolizable energy was also higher in the GM soybean [25].

Cottonseed meal, a by-product of the cotton industry, has been a component of cattle feeds because of its protein, fiber, and oil content that improves cattle growth and breeding ability. However, cotton seed contains a yellow phenolic pigment gossypol, which at high concentration in the diet, result to panting and reduced livestock performance. A pioneering work to reduce the gossypol in the cottonseed was conducted through genetic modification that interferes with the expression and activity of δ-cadinene synthase, the enzyme involved in gossypol production. The gossypol content in the foliage and floral parts of GM cotton were not affected maintaining the crop's ability to resist insect pests. This work allows the use of cottonseed to extract edible oil also for human consumption [26].

Safety of GM Foods

[27] Safety of GM crops and products has been a matter of concern for human health. Risk assessment on a case-by-case basis is critical for a country-level decision to allow or restrict GM foods. This is because various GMOs have different genes, which are inserted in multiple ways. Besides, studies used to evaluate the risk must take into account different populations and geographies. The WHO – FAO-led Codex Alimentarius provides detailed guidelines for assessing risks associated with GM foods. Typically, the following parameters are considered for risk assessment:

a) Toxicity-acute, sub-chronic and chronic.

b) Allergenicity, i.e. the potential to provoke allergic reaction due to cross reaction with other allergens or from new unknown GM proteins.

c) Composition analysis of major and minor nutrients to ascertain new or greater risks to nutritional status compared to traditional counterparts.

d) Nutritional effects associated with genetic modification that could arise if GM DNA is inserted into the crop genome at a location where it modifies the existing DNA such that the nutritional content of the crop alters.

e) Stability of inserted gene to avoid its unintended escape into cells of the body or to bacteria in the gastrointestinal tract. This is particularly relevant if antibiotic-resistant genes, used as markers while creating GMOs, were to be transferred.

f) Unintended effects that could result from the gene insertion leading to formation of new or changed patterns of metabolites.

Safety of GM Foods in India

In December 2017, a Parliamentary Committee report that examined the impact of GM crops on environment and human and animal health identified huge gaps with respect to the safety of GM crops. It noted the following key issues:

a) There has been no Indian scientific study carried out so far to study the impact of GM crops on human health.

b) Long-term effects on the human health have not been studied.

c) The Department of Health Research has not taken any action with regard to examination of impact of GM crops on human health.

d) The government should reconsider its decision to commercialize GM crops in the country as it has not been scientifically proven that GM crops have no adverse impact on human health. It is relying solely on studies that have not been done in India rather than on our own population and in the context of our climate and environment.

e) It is very late in the day for the FSSAI to take a decision to label GM foods imported into the country. However, the committee strongly recommends that labelling on GM foods must be done with immediate effect.

f) The committee also pointed out similar issues with respect to safety studies to evaluate the impact of GM crops on animal health and environment, both being potential routes through which GM crops and foods could impact human health.

Social and Economic Impact of Genetically Modified Crops

Social impact can be defined as: "The consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society." Only a few studies adopt a comprehensive approach and cover a wide set of social impacts of GM crops in agriculture. The review was limited to social impacts materializing at the farm level. Impacts occurring in other parts of the production chain (e.g., working conditions in the biotechnology industry or consumer impacts) were not included. General impacts on an aggregated societal level were only considered when relating directly to impacts at the farm level. Studies focusing on perceptions or attitudes about GM crops, without linking these to actual social impacts at the farm level, were not included. For example, while regulations on co-existence between farms producing GM crops and farms not producing GM crops might lead to social impacts at farm level for both farms, studies focusing on the impacts of co-existence on consumer choice or the willingness of farmers to adopt GM crops were not considered to be directly related to social impacts and were thus excluded from the review [3].

Farm-Level Impacts

Farmers have different socio-economic motivations for adopting GM crops. Significant socio- economic determinants include: gender associated aspects; individual and social learning; educational level; and expected benefits and uncertainty. For GM adopters, potential changes in yield and economic returns depend on current and previous crops and specific trait characteristics; agricultural practices; incidence of pest infestation; seed costs; and market characteristics. Farmers' production efficiency (farmers' ability to produce more with less than or equal inputs/resources) would also be affected, as well as the frequency of pesticide poisoning incidents and health impacts. Consumption of new bio-fortified GM crops is expected to increase farmers' nutrition status and as such, they could significantly contribute to farmers' well-being. The adoption of GM crops could have different impacts on wealthier and poorer farmers, which could exacerbate/mitigate social problems [29] Figure 2.

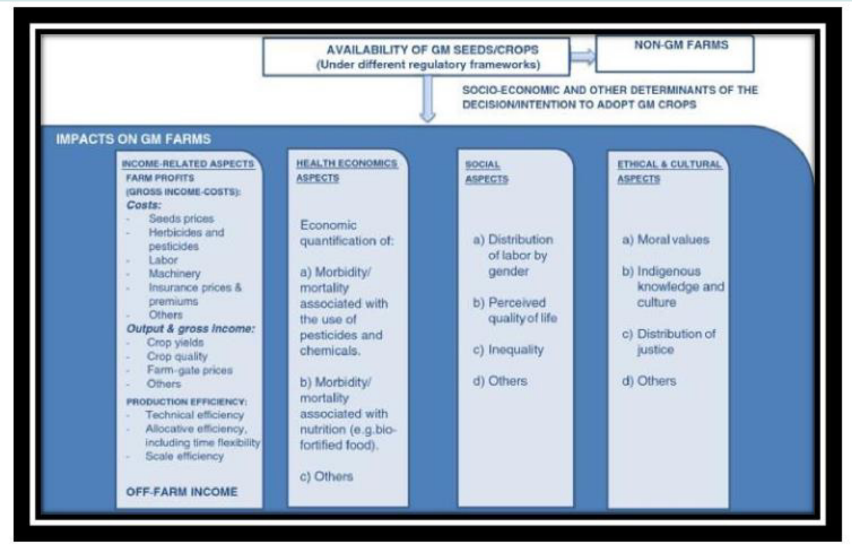

Figure 2: Conceptual Model of Socio-Economic Impacts on Farmers.

Coexistence Related Impacts

The possibility that GM farms contaminate non-GM farms via unintentional or inadvertent gene flow constitutes a challenge for the coexistence of GM farming and conventional agriculture, including organic certified agricultural systems. Several studies have analysed the effects that the introduction of ex-ante regulatory and ex-post liability aspects would have on farm-level costs and GM spatial configuration and adoption dynamics. In addition, potential benefits due to higher price premiums for non-GM products have also been evaluated [29-31] Figure 3.

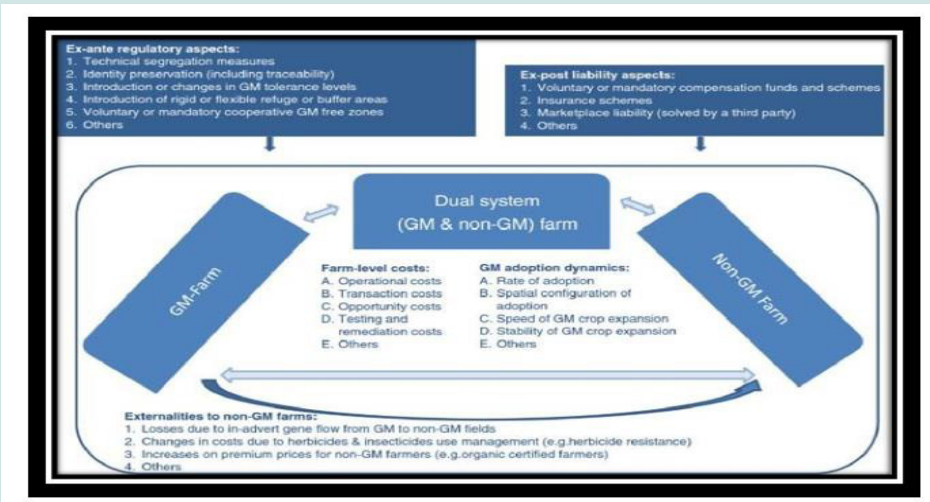

Figure 3: Conceptual Model of Socio-Economic Impacts of Coexistence.

Supply Chain Impacts

It aims to analyse the socio-economic impacts of the commercialization of GM crops on supply chain structure and performance dynamics, as well as cost and benefit distribution along different actors in the supply chain.

The main factors related to supply chain performance are:

a) Efficiency or the ability to deliver value at a minimum of total costs.

b) Effectiveness or the ability of the chain to provide superior value.

c) Innovation or the ability to respond to changes in consumer demand or the external environment.

Several studies have analysed the effect that the commercialization of GM crops would have on the supply chain structure, as well as the distribution of costs and benefits of different actors along the supply chain. Moreover, governance mechanisms and market power of different actors would also be affected [29,32] Figure 4.

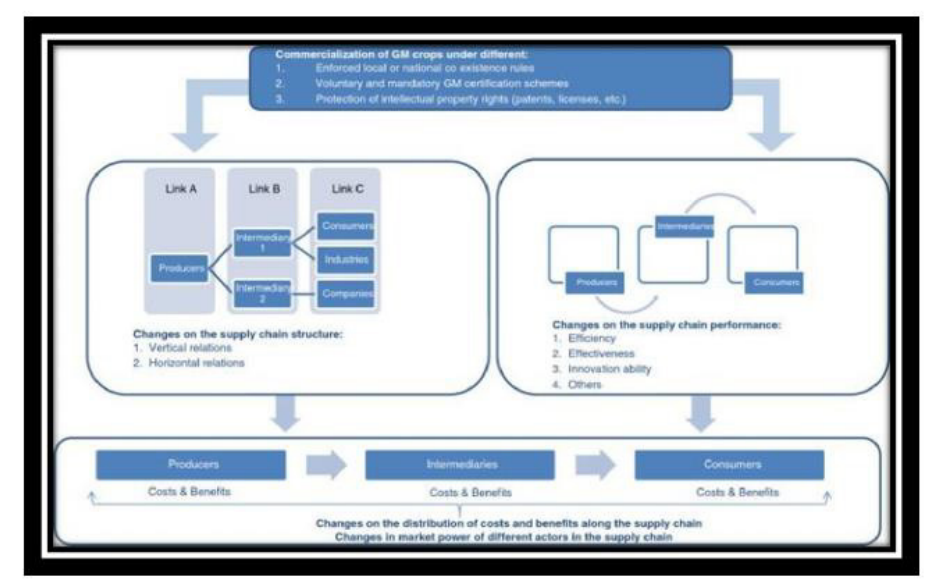

Figure 4: Conceptual Model of Socio-Economic Impacts along the Supply Chain.

Consumer-Level Impacts

The socio-economic determinants for consumers' acceptance of GM food and the associated price premiums for non-GM products have been evaluated under different mandatory and voluntary GM-related label schemes. Other studies have evaluated the option values of a moratorium or ban on GM products. Those price premiums and option values have been used to calculate economic welfare effects [29,33] Figure 5.

Figure 5

Environmental Economic Impacts of GM Crops

GM crops may substitute for agricultural inputs and practices that are environmentally harmful. The study by Brookes & Barfoot suggest that "since 1996 the use of pesticides (counted as active ingredients) on the GM crop area was reduced by 448 million kg (9% reduction), and the environmental impact quotient-an indicator measuring the environmental impact associated with herbicide and insecticide use on these crops-fell by 17.9%. In 2010, the total carbon dioxide emission savings associated with GM crop adoption were equal to the removal from the roads of 8.6 million cars due to reduced fuel use and additional soil carbon sequestration".

GM crops can cause environmental harm as well (although there is considerable uncertainty and no consensus among scientists). In particular, the protection of biodiversity and ecosystem services ought to be a top priority when taking into consideration the dependency on a healthy environment of all human activity, now and in the future. For those opposed to GM technology, GM crops are exotic species being introduced into open complex ecosystems of which we have limited understanding, and as such it is impossible to anticipate all impacts of GM technology on the environment. The effects of GM crop adoption on the environment will depend not only on human behavior but on biological, ecological, and chemical interactions as well. Many disciplines are needed to evaluate these kinds of impacts. In addition, there is the possibility of irreversible ecosystem disruptions due in part to the unpredictable and novel effects of gene mixing [29] Figure 6.

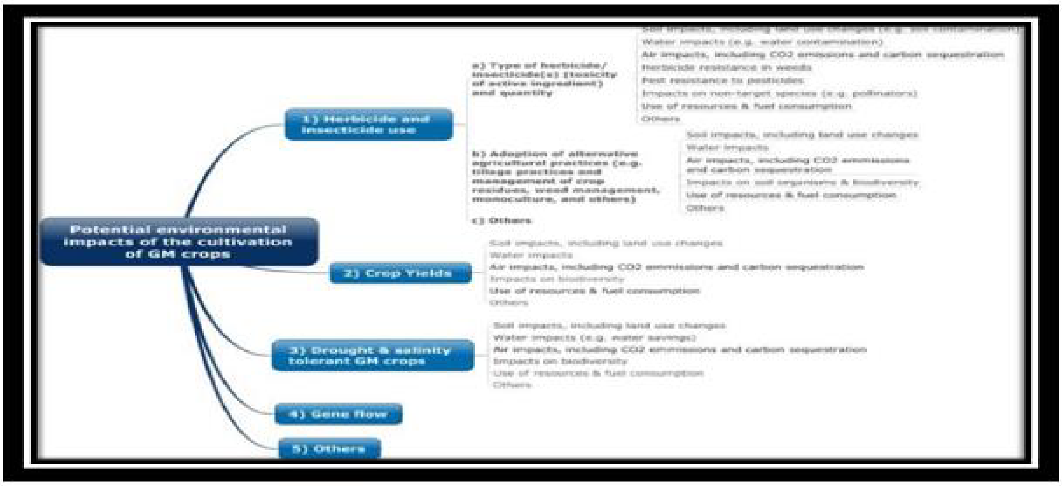

Figure 6: Conceptual Model of Environmental Economic Impacts of GM Crops.

Food Security at Household Level

The estimated number of undernourished people has continued to decrease, but the rate of progress still appears insufficient to reach international goals for hunger reduction. Currently, about 842 million people (one in eight people in the world) suffer chronic hunger, unable to obtain the amount of food necessary to conduct an active life. Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets dietary needs and food preferences for an active and healthy life. There are four dimensions of food security: food availability (e.g., food production and processing); food access (e.g., having the economic resources to buy the right food); food utilization (e.g., education to individuals to make proper use of healthy food); and food system stability (e.g., adequate access to food at all times). For food security objectives to be realised, all four dimensions must be fulfilled simultaneously. Therefore, food security is a multidimensional concept, and data on all dimensions are rarely available and frequently unreliable. In relation to GM crops, reports from expert governmental and nongovernmental bodies increasingly include GM crops as part of a wider approach to food security. GM crops could help to mitigate expected food shortages related to population growth and the effects of climate change in specific regions worldwide. For example, GM crops could impact food availability by providing seeds which are resistant to adverse climate conditions; have an effect on food access by increasing farmers' incomes; and, under the same food utilization conditions, bio-fortified crops could increase the nutritional status of households worldwide [29] Figure 7.

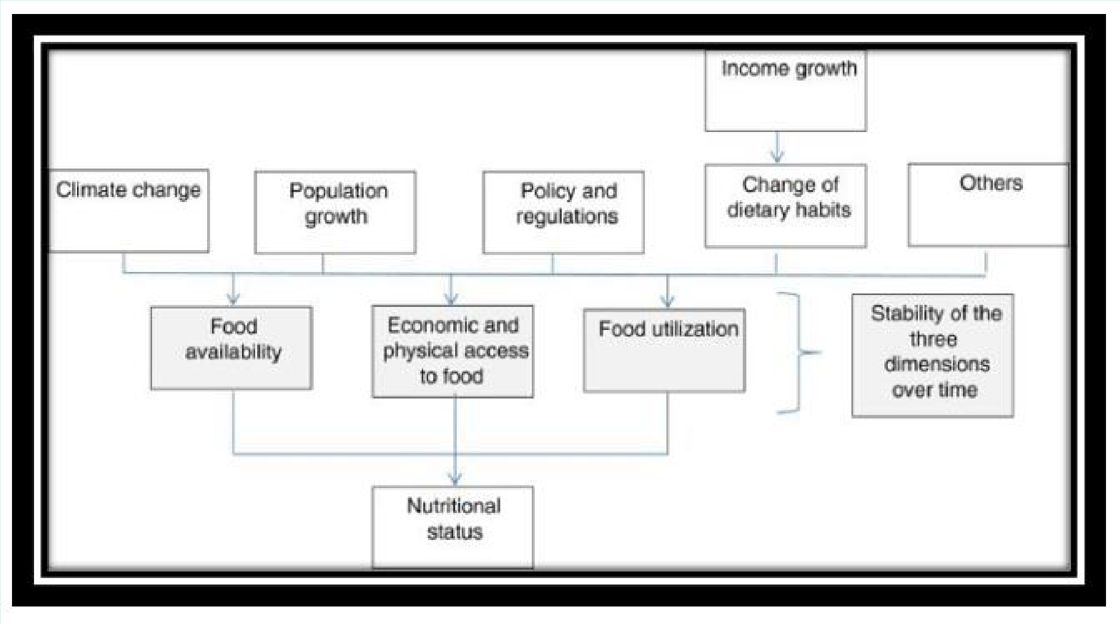

Figure 7: Conceptual Model of Food Security at Household Level.

Economic Benefits of GM Foods

From 2006 to 2012, the global increase in farm income from GM food had reached $116 billion, almost triple that of previous 10 years. According to the estimation from James and Brookes, 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% [34].

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