University of Nevada, Reno

# The Impacts of Genetically Modified Organisms That Increase Yield and Nutritional Values and Their Future Applications in Assisting the Humans

A thesis submitted in partial fulfillment

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We recommend that the thesis

prepared under our supervision by

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Amy Altick, Ph.D., Thesis Advisor

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## Abstract

The growth and adequate feeding of the human population are critical concerns. As more people are born, the faster the Earth's resources will become insufficient. One way of tackling the overpopulation problem is genetically modified organisms, or GMOs, that increase the nutritional value of foods. During the past several decades, GMOs have been useful to countries that face malnutrition or food deficiencies. An example of a very prominent food deficiency is vitamin A deficiency. Vitamin A deficiency is prominent in many Asian and African countries (WHO 2016). To ease those suffering from the health issues associated with vitamin A deficiency, a humanitarian project called Golden Rice was initiated by research teams in Europe. Golden rice is genetically engineered rice with enhanced vitamin A content. However, despite strong support from both scientists and researchers, there is still doubt and concerns from many members of the general public regarding the ethics and use of nutritionally-enhancing GMOs, such as Golden rice. This thesis discusses the findings of many research teams and their work with nutritionally-enriched GMOs, like Golden rice and the legumes- peas and soybeans, in regards to their production, safety, and benefits.

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## Introduction

In today's world debatably, two of the biggest issues that humans face are overpopulation and malnutrition. Not a single other factor, be it war or environmental disaster, pose such a threat to humanity than not being able to sustain and adequately feed the Earth's population (Nooe 2013; Kuo 2012). Over the course of history, the human population began by growing very slowly, but with generations, the growth rate has rapidly increased. Scientists and scholars around the globe are concerned that at the current rate, the Earth's population will reach eight billion by the year 2028 (Foley 2013). From 2028 forward, because human growth rate is exponential, there will be a sharper increase in the number of people, as more and more people reproducing. A higher density of people not only requires more resources such as food, but also negatively impacts the available reserves, such as fresh water and open farmland. Overpopulation is defined as "the ability of the land to support a given number of people under the existing technology and relevant resources, such as, water and essential nutrients they need to survive." (Campbell 1991). With increased population and thus the threat of overpopulation, sociologists and scientists have begun to investigate methods of sustaining this huge population increase with the remaining of available resources. It is notable that the media frequently airs stories concerning the world's limited reserves and at the same time popularize extreme solutions such as colonizing Mars (Ashok 2016). Ideas of this sort seem reasonable because global resources are strained and the sustainability of the planet is in doubt.

The effects of overpopulation range from depletion of resources and increase of pollution to lack of fresh water and open space for agriculture. These environmental issues are coupled with a myriad of social problems, including starvation, food deficiencies and malnutrition, all caused by rapidly increasing population density. Developing countries, like Somalia, Indonesia, India, and others are most vulnerable to these effects, due to their paucity of resources. However

even countries with better access to resources such as the United States and members of the European Union, face the same issues as their populations continue to increase (Pimentel 2003). It is projected that by 2043 most countries will need to double the amount of food that they are currently producing (Foley 2013). However, the challenge of feeding everyone is not just an issue of volume but also an issue of nutritional value of the available food. Overpopulation and malnutrition are prominent issues that are forcing many individuals around the world to consider those affected and take action. Fortunately current technology can improve food quality, increase the amount of food produced, and add nutritional value to existing food sources via genetically modifying organisms.

Genetically modified organisms (GMOs) were developed in the early 1980s and first approved by the U.S. Food and Drug Administration in 1982 (Junod 2009). Since 1982 the range of products that have been developed via genetic modification has steadily increased. Today genetically modified organisms are used in a wide variety of applications from vaccines and medications to food products and pesticides. However, as the use of GMOs increases, so does public awareness. Fears regarding environmental and health safety are expressed by public stewards and scientists alike. Because GMOs have been depicted as “artificial” and “unnatural,” many people around the world are hesitant to accept or use GMOs. Another misconception is that all GMOs are the same, and while the biotechnology used to create GMOs is similar, each GMO product is unique. Several of the public’s most common fears about GMOs will be addressed in this paper. More importantly, this thesis aims to provide the necessary information for the reader to understand and make their own decision regarding the use of GMOs.

There are many different applications and types of GMOs, as stated above, however, this thesis will focus on those GMOs that increase the nutritional value and yield of foods, thus

providing more resources to support human life. The two particular examples that will be used to evaluate the concerns surrounding GMOs are Golden rice and the legumes, soybeans and peas. Golden rice is engineered to biosynthesize beta-carotene, thus enhancing every grain of rice with higher levels of vitamin A (Ye et al., 2000). This provides an essential nutrient in the rice, which is especially important in Asian countries, where vitamin A deficiency causes 13.8 million children to have some degree of visual loss related to poor dietary intake. The World Health Organization estimates that annually 500,000 children across the globe go completely blind because of vitamin A deficiency (WHO 2016). Another GMO that could lessen the food shortage crisis is genetically modified soybeans and peas, which have been designed to have boosted fungal and bacterial resistance. In addition these legumes are enhanced in the sulfur-rich amino acids methionine and cystine, the former being an essential amino acids that the human body cannot synthesize (Herman 2003). These two GMOs, exemplify the scientific and technological advances that can provide benefit to populations all over the world. As mentioned this technology is not new and has been government approved for decades in the United States (Bawa et al. 2012). Importantly, GMOs that increase nutritional value of foods may open new doors for the human race in its need to support its ever growing population.

# CHAPTER 1

## Science of GMOs

All life on Earth is the same in the sense that it is comprised of cells that contain the entire genetic information of the organism. Every cell contains long chains of deoxyribonucleic acid, or DNA, which is a complex molecule that is made of two long chains of building blocks called nucleotides. DNA is three-dimensionally shaped like a double helix, representing a spirally twisted ladder. Genetic information is encoded in specific sequences of four different types of nucleotides- thymine, adenine, guanine and cytosine, abbreviated as T, A, G and C respectively. The information in DNA is sub divided and stored as genes, which are the functional units of heredity for all organisms. Genes are unique sequence of nucleotides, comprised of many A, T, C, and G in a very specific order. Genes transmit genetic information from parents to offsprings. Just like words in a language are made up of letters, so are genes made up of specific nucleotide sequences (Smith 2006; Mai 2005). It is the arrangement of those letters that creates variations and uniqueness in organisms and thus the enormous amount of diversity on planet Earth. Figure 1 shows the similarities and differences between the DNA of humans and chimpanzees and illustrates how all life on Earth is remarkably similar with just slight variations in the sequence of nucleotides. The slight variations, starred, are what give rise to different sets of proteins which account for the differences between a human and a chimpanzee.

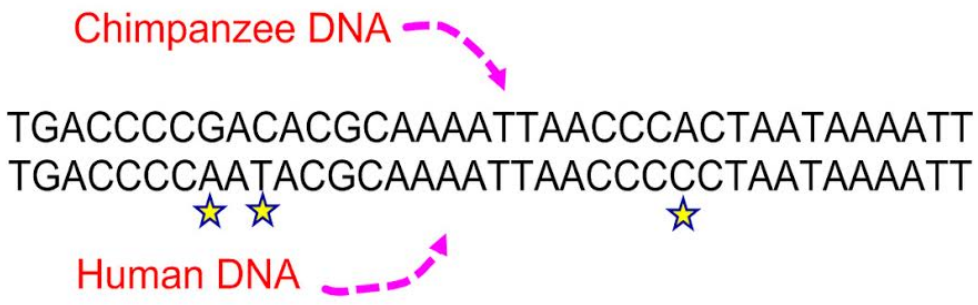



**Fig. 1. DNA of a chimpanzee and a human.** Similarities and differences between part of a DNA from humans and a part of DNA from chimpanzees (VanCott 2016).

Although there is a great amount of commonality among species, in terms of evolutionary ancestors, presence of DNA, and the many physiological and biochemical processes that are the same in every living organism, it is the slightly different arrangements of nucleotides found in different sets of genes that give rise to the differences among organisms. All living organisms, including single-celled micro-organisms and fungi, carry copies of all their genes in their cells and thus the information necessary for translation or the creation of all of the proteins that an organism requires to live. Translation is the careful reading of the information stored in genes' sequence of A, T, C, and G and coding this information into a new language- such as a functional protein. Figure 2 illustrates what biologists call the Central Dogma, in which a piece of DNA (string of nucleotides) is converted to a functioning protein, during a final step called *translation*, through a series of biochemical processes and steps involving many enzymes. The Central Dogma is an example of a conservation among species because translation is an essential process in every living organism. Proteins are a macromolecule made up of one or more long chains of amino acids and the order and the type of amino acid present are what defines the protein. There are a total of 20 amino acids available to produce a protein and nine of them are essential, meaning that human body cannot synthesize them naturally and that is why they have

to be derived from a healthy diet. The information stored in different genes is translated thus producing a certain type of protein, including enzymes, structural proteins, regulatory proteins, motor proteins, transport proteins, and many more**.** Enzymes are a special type of proteins that speed up all reactions in an organism's body, including glycolysis or other biochemical processes that fulfill the energy needs of the organism. These biochemical processes convert the long DNA of an organism, made up of millions of nucleotides in a string, to a functioning protein. These processes are conserved among species and are essential to all life on Earth.

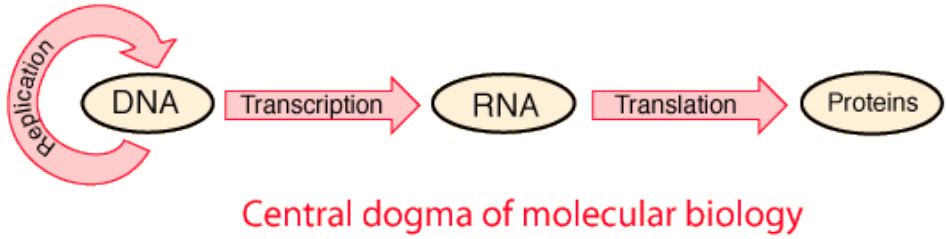
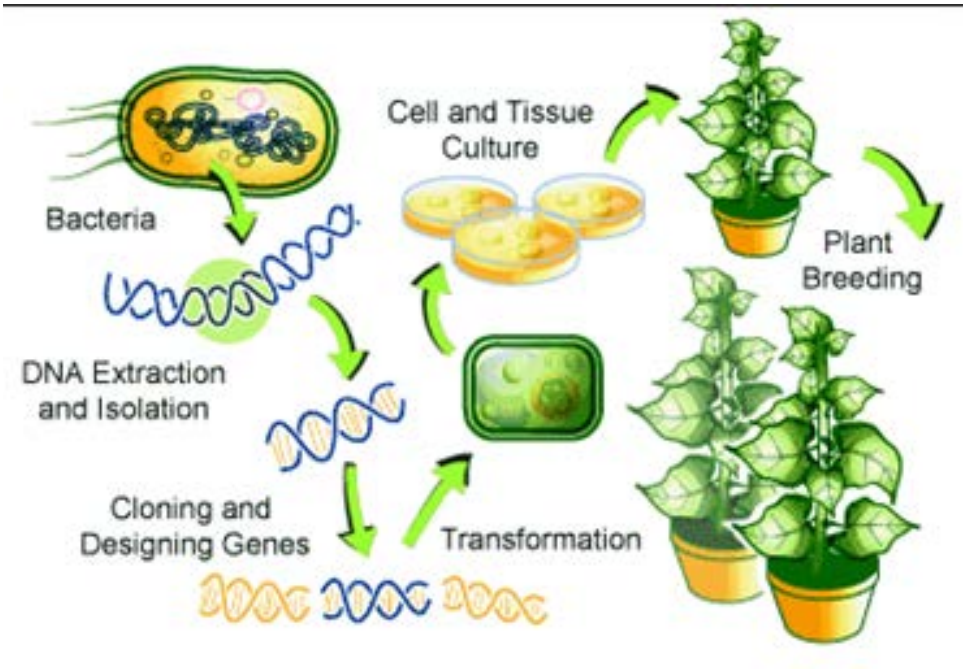



**Fig. 2. Central Dogma of Biology.** An explanation of the flow of genetic information within a living organism ("Central Dogma").

Because of the universality of the genetic code and protein synthesis as well as the huge conservation of which gene codes for what protein, across species, the foundations are set for genetic modification. Genetic modification, or bioengineering, is the process of altering the genetic material of an organism by use of methods that do not occur in nature. In other words, it is possible to know the type of protein or function that a gene is responsible for producing and by selecting the string of nucleotides that make up this gene in one organism, it can be imbedded into the DNA of another organism giving the latter the trait for which the gene was originally responsible. This process involves, isolating and removing the string of nucleotides that encode a single gene in one organism and inserting it into the genome of another organism (Bawa et al.,

2012; Xu et al., 2014). Organisms that have been modified through genetic modification are known as genetically modified organisms, or GMOs. In other words, those are organisms whose genes have been artificially altered to modify their characteristics in some way or another. Genetic engineering is a complicated process that generally requires the following: first the DNA from an organism with desired trait needs to be extracted and isolated. Secondly, scientists use DNA amplification to separate the single gene of interest from the rest of the genes extracted and make thousands of copies of the gene of interest. After this, comes gene design, which modifies the gene to work inside a different organism and thus introducing the selected trait into the host's genome. This process is done in a test tube by cutting the gene apart with enzymes and replacing gene regions that have been separated. Lastly is *transformation*, or inserting the gene into the organism one wishes to modify. Figure 3 illustrates how genetic engineering is achieved and shows what happens during the multistage process of bioengineering.



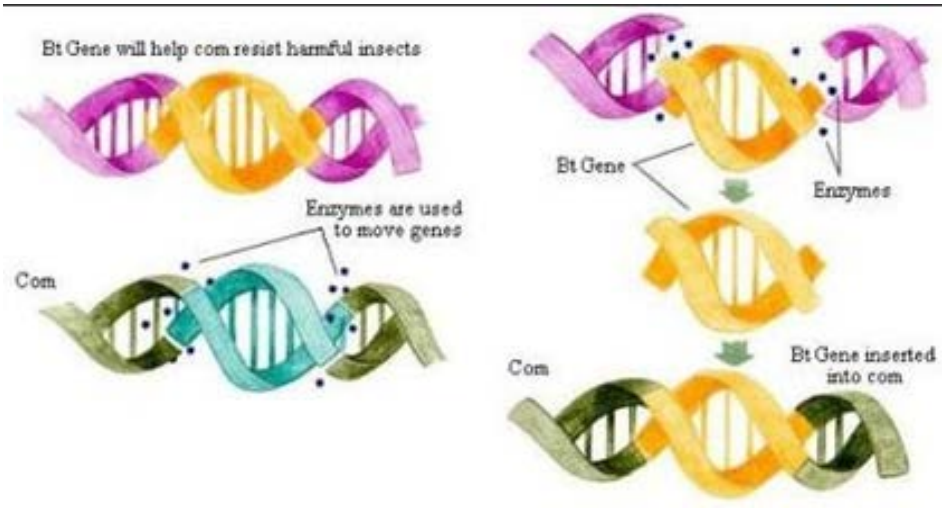



**Figure 3. The process of bioengineering.** The overall process of how to produce a GMO, including the identification and isolation of gene of interest and transformation into the genome of the final product, which in our case is rice or legumes (**upper**). Bioengineering at the molecular level, which shows details of how a gene is isolated and inserted into the genome of a different organism (**lower).**

Below is a detailed step-by-step process of how to produce a GMO:

1. Identification of the gene interest (using multiple databases)
2. Isolation of the gene of interest (using restriction enzymes, serving as a molecular scalpel)
3. Amplifying the gene to produce many copies (using the enzyme Taq DNA polymerase, to synthesize exact copies of the gene)
4. Associating the gene with an appropriate promoter, the site that initiates expression of the gene of interest, and poly A sequence, to initiate correct process, and insertion into plasmids (a plasmid is essential for bioengineering as it is capable of replicating independently of the chromosomal DNA)
5. Multiplying the plasmid in bacteria and recovering the modified gene for transformation into the target organism
6. Transference of the modified gene into the recipient tissue, usually fertilized eggs (this process is called *transformation*)
7. Integration of gene into recipient genome (this step requires multiple attempts and then confirmation for successful integration)

8. Expression of gene in recipient genome (thus modifying the target organism permanently)

All of these steps require an extensive amount of testing, including the safety, side effects, and others, and includes federal agencies, such as the FDA, and other independent research groups. Such testing procedures follow similar protocols to newly developed drugs and often require years to complete (Xu et al., 2014). For example, insulin was formerly collected from humans and animals and thus carried a risk of transmitting disease. Now, with the use of genetic modification technology, pure and safe equivalents can be produced using GMOs. Industrial scale quantities of insulin are produced by growing bacteria in fermenters (Hall 2012). Theoretically, genes from virtually any living thing could be extracted, modified, and then introduced into a different organism. Many will agree that science aims to make new discoveries that could potentially make human life better. That is why scientists who design GMOs follow the same credo and only do so in order to create a stable and better combination of suitable traits. The target gene in a given organism and the selection of a suitable host is a very careful and precise process directed to producing an organism with enhanced characteristics, be those better resistance to pests, immunity to infection, or increased nutritional value. This paper will focus on those GMOs that involve only plants or certain bacterial species. Those genetically modified organisms that have been modified using animal genes or any part of an animal's genetic code are not discussed in this paper and thus the term GMO, as it is used in this paper, does not consider this type of GMOs.

# CHAPTER 2

## Types and Background on GMOs

There are many different types of genetically modified organisms, including GMOs designed to have higher resistance to pests or micro-organisms, those designed for medical purposes, GMOs with increased herbicide tolerance, GMOs with delayed ripening, and GMOs with increased nutrients. This paper focuses exclusively on the last group and although many of the arguments put forward apply to GMOs as a whole, nonetheless they will directly concern and address only those GMOs that increase nutritional value of foods. Moreover, the focus is entirely on GMOs that not only enhance nutrient content, but also exclude any form of any animal's genome and only discuss GMOs designed using bacterial or plant genes. The specific examples that will be discussed are Golden rice and the legumes: peas and soybeans. The development of Golden rice was founded as a humanitarian project and designed for countries with prevailing cases of vitamin A deficiency, which results in subsequent health impacts (Paine et al., 2005). GMO peas and soybeans are an example of crops that have been modified to provide an increased nutrient value (Herman 2003). Providing more nutrients for the same production cost and price may be one method to tackle the problem of feeding the ever-growing global population.

The history of GMOs dates back to 1983 when the United States Food and Drug Administration, FDA, approved the first genetically engineered drug humulin, a form of insulin produced by bacteria. Humulin, the first GMO was created in 1980 and two years later it was approved by the FDA. Humulin became the first product available to the public that was developed through modern bioengineering (Hall 2012). Although, humulin is the earliest official GMO, the idea of modifying or selecting traits has been used by farmers all throughout history.

Farmers are known to have used selective breeding, or selecting the best and strongest of two plants and manually cross-pollinate them to create an offspring that would have better traits and characteristics than its parents. This was possible as early as the late 1800s thanks to the work of Gregor Mendel, who proved the idea of inheritance and thus trait selection in peas. This goes to show that humans have always sought to increase yield and size of crops, they just did not have the technology necessary to do so efficiently. During the 1940s and 1950s science and research teams began exploring the possibility of introducing genetic variation into the genome of an organism and in 1973 recombinant DNA was created, which allowed for man-made DNA, or rDNA, to be created (Bawa et al. 2012).

In 1987 the preliminary field tests of genetically engineered crops, such as tobacco and tomatoes, began to be conducted in the United States and by 1993 Flavr Savr genetically modified tomatoes were approved for commercial production and soon after became available in American grocery stores. This was the same year that the FDA declared GMOs as “not inherently dangerous” and that is why they do not require to pass any other special regulations (Dubock 2014). Genetically modified organisms, that increase nutritional value of foods, began as a research project that started off as a Rockefeller Foundation initiative in 1982. After years of research, by various research, a meeting of experts was convened in New York in 1992 and exactly ten years later in 2002 Golden Rice was created by Professor Peter Beyer and Ingo Potrykus of the Swiss Federal Institute of Technology (Burkhardt et al., 1997). Corn and soybeans with enhanced nutrient content came out in 2008 and have been circulating the U.S. market ever since.

# CHAPTER 3

## Why Develop Nutritionally-enriched GMOs

If one looks at some of the history of mankind, he will eventually notice that simply from the observation of natural crops, farmers found that cross breeding of certain crop plants resulted in better products. They learned, “to combine the desirable characteristics of two plants to improve the performance and varieties of different crops.” (Moghissi et al., 2015) Alan Moghissi is one of the world’s most renowned scientist and researcher in the area of genetically modified organisms. He is an expert who has dedicated his life to studying and researching various questions regarding GMOs. According to Alan Moghissi himself, he was skeptical of the idea of genetically modified organisms at first, but then he realized their potential and numerous applications. Moghissi writes of the benefits of GMOs and constantly addresses newly emerged criticisms against the safety of GMOs. His research publications have been cited some 1,500 times and research teams all over the world use his work in a variety of ways. Moghissi states that, the global community has had to deal with a variety of adverse events such as droughts, floods, proliferation of a variety of insects, lack of necessary soil nutrients and many other problems. It is safe to assume that these negative events have driven the human race to look for new and improved ways to eliminate and reduce such issues and the scientific and agricultural advancements of the past decade were a direct result of the need for better sustainability. One such advancement is genetic engineering which is the key process in designing genetically modified crops. Moghissi has identified three distinct objectives for GMOs: 1) to improve the production of the crop by accelerating its growth, 2) to make the crop resistant to insects, pathogens, and other pests, and lastly 3) to improve the crop’s nutritional quality (Moghissi et al., 2015).

Asia is the world's largest producer and consumer of rice. Rice is the primary dietary staple, with an estimated 350 million tons being consumed annually (Mohanty 2013). Asia is also plagued with poverty and infectious diseases. Due to the lack of adequate nutrients in the diet, combined with the absence of dietary diversity a rise in vitamin A deficiency has been observed in the region. According to statistics by Moghissi, the most affected Asian countries in 2005 were India and China. The number of affected individuals from these two Asian countries combined with the majority of African countries is a huge cause of worry. Overall more than 190 million children and approximately 19 million pregnant women in a total of 122 countries around the globe are affected by vitamin A deficiency. Vitamin A deficiency is responsible for 2 million deaths and about 500,000 cases of irreversible blindness annually. In addition vitamin A deficiency reduces immune defenses making an individual susceptible to infections and disease (Gerster 1997). These number highlight the magnitude of the issue and it is evident that all of this is a real problem for many people and it shows how something as simple as a vitamin not present in one's diet can have dire consequences to global health and wellness (Gerster 1997). The urgency for a solution to address this problem is also evident and that is why teams from around the world have looked for ways to help those who suffer from vitamin A deficiency.

Golden rice is a ground-breaking innovation that has changed the lives of many people. Golden rice, is a humanitarian project because its creation was due to the prevailing number of vitamin A deficiency cases around the world. The mission of the research teams involved was to aid those who suffer from vitamin A deficiency effectively and without changing the dietary habits of those affected (Ye et al., 2000; Mohanty 2013). Golden rice fulfills the third objective of GMOs that Moghissi described. It was developed in 1993 with European scientists focused on introducing suitable genes into rice to enhance nutrition (Datta 2000). Golden rice was created

by transforming regular rice with a two separate beta-carotene biosynthesizing genes, phytoene synthase, or *psy* and carotene desaturase, or simply *crtl*. The *psy* gene comes from a Narcissus plant while the *crtl* gene is derived from the soil bacteria Erwinia (Burkhardt et al., 1997). After the two genes are transferred into the rice's genome they are placed under the control of a promoter, a site that regulates the reading of the nucleotide sequence. A promoter controls gene expression, so the protein produced is functional in the endosperm, or the nutrient store of the developing embryo. The production of these two proteins gives the rice a distinctive yellow color for which it is named. The team behind the design of Golden Rice have provided a possible solution to the ever-growing concern of vitamin A deficiency. They have even found a way to not change those individuals' diet and have transformed their most common food into a superfood that is not only more nutritionally-enhanced, but also an effective mean to tackle a condition that is very prominent and affecting the lives of many.

Kathleen Hefferon the author of Nutritionally Enhanced Food Crops; Progress and Perspectives, says that she, as a scientist and humanitarian is "very pleased that scientific and agricultural advancements have happened in order to allow for the design of genetically modified organisms, such as Golden rice." (Hefferon 2015). Dr. Hefferon along with Alan Moghissi speaks of the benefits and importance of Golden rice for many countries in which vitamin A deficiency is an issue. In addition to discussing the benefits of Golden rice, Dr. Hefferon also mentions genetically modified legumes, specifically soybeans and peas. Genetically engineered soybeans and peas fulfill all three objectives that Moghissi described, in that they have heightened bacterial and fungal resistance to legume pests, such as stink bugs and ear worms. Genetically modified peas and soybeans, just like Golden rice, increase the nutritional value of the product as they now contain more proteins per pound as well as higher amino acid content.

Thanks to genetic engineering these soybeans and peas require less time to grow, thus reducing costs and increasing efficiency. These legumes are designed by introducing the gene that codes for nitrogenase enzyme from a rhizobium bacteria and incorporating into the legume's genome (Herman 2003). These GMO legumes have the promise to deal with feeding Earth's ever-growing population. In addition, another benefit for developing countries is that the technology can be imported allowing such countries to produce their own GMOs, no longer relying so heavily on imports as they are now able to produce their own soybeans and green peas. Research teams from developing countries can be introduced to the technology and trained in how to perform the steps necessary to produce GMOs, thus spiraling their own economies in the positive direction (Herrera-Estrella 2000).

Even though, both research professors speak of the many benefits of GMOs, such as Golden rice and soybeans, many individuals seem hesitant to use them as they are not "natural." Despite the fact that Golden rice was received extremely well by every country in which it was introduced, there is still a number of politicians, scientists, and reporters who consider genetic engineering unethical and push for its worldwide ban (Bonny 2003; Hunt et al., 2012; Lin 2016; Schwartz 2013). So which are the two sides of the debate for or against GMOs and how does each side defend or criticize its argument?

# CHAPTER 4

## Sides of the Debate Surrounding Safety and the Use of GMOs

Over the past few decades, the European Union (EU) and the United States (US) have implemented some very different regulatory policies to govern the consumption and production of GMOs. In the United States, many genetically modified organisms have been tested and commercially marketed and produced. On the other hand, in the EU, 19 of its most developed 28 members have completely banned the use, importation, and production of genetically modified organisms (European Commission 2016). These different approaches to policies regulating GMOs have led to a debate over the safety of genetically modified organisms and have also become one of the major stumbling blocks to securing a free trade agreement between Europe and the United States of America. Washington, D.C. demands that Europe lifts restrictions on imports of these genetically modified foods, but the European Union remains skeptical of their safety (Sheldon et al., 2002). Intense emotions and propelling arguments from both sides of the GMO debate make it difficult for a consumer or a citizen in either continent to make a choice in regards to his own use of genetically modified organisms.

So what are the differences between regulations of genetically modified organisms in the EU and the USA? Firstly, the United States does not have any federal legislation in place that are specific to genetically modified organisms. Rather, the use and production of GMOs is allowed in the country until there is a probable cause to suspect GMOs of having negative effects on health, safety, and the environment. The US approach to regulating GMOs is premised on the assumption that regulation should focus on the nature of the products, rather than the process in which they were produced. Furthermore, the FDA has passed a legislation that allows companies and manufacturers to not label whether or not they use genetic engineering in their production

process (Dubock 2014; Haselkorn 2013). Compared to other countries, regulation of GMOs in America is very favorable of the development and use of GMOs. GMOs are an economically important component of the biotechnology industry, which now plays a significant role in the US economy. For example, the US is the world's leading producer of genetically modified (GM) crops. In 2012, of the 170.3 million hectares of biotech crops globally, the United States accounted for 69.5 million, over 40% of the total. For several crops grown in the US, genetically engineered varieties now make up the vast majority of the crop. In 2013, 93% of the soybeans, 90% of the cotton, and 90% of the corn grown in the US were genetically engineered for either herbicide tolerance or insect resistance (James 2014). Today there are many companies that produce GMOs, the largest producer of which is Monsanto with headquarters in the United States. Monsanto currently holds about 70% of the global market for genetically modified seeds and products. In 2006, the company reported a global revenue of $7.344 billion (Anino 2015). The other major players in producing genetically modified organisms are Syngenta, BASF, Dupont, Bayer, and Dow Chemical Company. Together with Monsanto, these six companies are collectively called the Big 6 Pesticide and GMO Corporations.

The FDA has published its policy regarding GMOs online so that any one interested could read it and the FDA cite a study that was written in 1990, the year when GMOs first started to become popular. In this study every single possible thing that could go wrong is listed as a consideration that the FDA must not overlook. The criteria is exhaustive and it includes areas, such as what effects do GMOs have on the environment, the ecology, pesticide effects, and conservation of species, as well as how GMOs affect all animals and not just humans. The criteria for humans is the largest and it encompasses everything from proteins, carbohydrates, fats, metabolic and biochemical processes, the DNA molecule, and many others. The study is

titled "Biotechnologies and Food: Assuring the Safety of Foods Produced by Genetic Modification" and its main purpose is to provide a comprehensive list of things things that the FDA must consider when deciding the safety of a GMO. It is the FDA's policy that if there is even the tiniest of evidence against a GMO that is currently in development and thus the GMO fails one of the criterion outlined in the study, then this GMO will not pass preliminary safety tests and not get to clinical trials, thus never becoming available. Since, there is a huge number of GMOs, way more than the FDA can handle alone, the FDA needs assistance and that is why the agency relies on independent research groups and teams to provide experimental data regarding a GMO. When a GMO is first introduced for possible commercial, agricultural, or public usage, many independent teams, mainly those opposing GMOs begin conducting experiments and research aimed at gathering enough data and evidence to suggest that the GMO in question does not meet one of the criteria outlined in the reference study. For the FDA there is no such thing as bias. Teams working for the FDA look at every piece of evidence from research teams all over the world and not just American scientists. What this means is that a European research team could conduct an experiment and find a flaw with a certain GMO, after which the FDA will confirm the results and prevent the GMO from ever becoming available. The FDA goes over thousands of research findings regarding the safety of GMOs annually and year after year American and international scientists fail to provide conclusive enough evidence against GMOs.

The European Union on the other hand, has a comprehensive and strict legal regime on GMOs. Any food produced by genetic engineering is completely banned in 19 out of the union's 28 members, including countries such as Germany, France, Scotland, France, Italy, Austria, Greece, Poland, and Belgium (Chow 2015). The European Union's legislation and policy on

GMOs, are designed to prevent any unforeseen consequences on the environment and the health of individuals. According to the EU, safety of humans and animals is their number one priority and it reflects concerns expressed by skeptical consumers, farmers, and environmentalists. Such policies against GMOs arise in the European Union mainly because of the high number of scientists living in Europe, who believe that GMOs are bad. A high number of scientists publishing anti-GMO studies have a tremendous impact on the European governments and that is essentially why a ban on GMOs is observed in Europe. Genetically modified organisms could potentially be marketed in or imported into the EU, however they are only authorized after passing very strict evaluation and safety assessment requirements that are imposed by regulating agencies and as a result, only a very small percentage of GMOs are actually allowed to be imported. Unlike the United States and its policy in labeling GMOs, the EU requires that any GMOs that enter its borders be assigned a unique identifier and be labeled as such to ensure traceability and enable consumers to make informed choices.

The European Union has not always opposed to genetically modified organism and in fact did not have such strict laws and regulations until October 3rd of 2015. Before 2015, the European Union had no issues with GMOs mainly because genetic modifying was so popular in the United States and after performing series of tests on their own, the European Commission arrived to the same conclusions that the FDA did, further assuring the safety of GMOs. However, after almost 4 years of debates by politicians, scientists, researchers and the media, it was finally decided to restrict GMOs. So what influenced this decision of the European Commission? For starters, Europe has much stricter and complex environmental policies than the United States does. The European Commission for Environmental Safety has stated that there is just not enough evidence and research findings to label GMOs completely safe for the environment and

until all possible hazard is ruled out, it is simply not a chance that the European Union is willing to take. The U.S. on the other hand, has an approach that allows for the use of GMOs as they have proven to benefit large areas of the American economy. It is a practice that has worked tremendously well and so far there is not any evidence linking GMOs to any harmful consequences to the environment, regardless the efforts of many groups to do so (Bonny 2003; Hunt et al., 2012; Kvakkestad 2007). Just one example of the irony in this argument against GMOs is the fact that there are major oil spills every once in a while that have horrid consequences for the environment, including animal and plant life, conservation and ecology. But not nearly as much attention is paid when that happens and all disciplinary actions against those in fault are large money settlements that are just a fraction of the oil company's profits anyway. Another factor that influenced the difference of decisions between America and the European Union regarding GMOs, is interest groups. Many interest groups were afraid and scared of genetic engineering, thus labeling it unsafe and unethical. Many of the fears were health related, including fears that GMOs can cause cancer, autism, or other serious conditions (Edwards 2015; Hunt et al., 2012; Lin 2016; Schwartz 2013). In the United States, interest groups saw the potential benefits that GMOs will have, both domestically and worldwide, and through the legal practice of lobbying provided a positive outlook on GMOs that many politicians saw as something that will benefit the American public. And they were right. The United States of America ranks behind Germany, France, the United Kingdom, Belgium and other European countries that have GMOs banned in death/mortality rate. The U.S. has 8.15 deaths per 1000 population while, Germany, France, the United Kingdom, and Belgium have 11.42, 9.16, 9.35, and 9.63 respectively (CIA.gov). In terms of cancer patients, Denmark, Belgium and France all rank higher than the United States per 100,000 population, with 326.1,

306.8, and 300.4 for Denmark, Belgium and France respectively, while 300.2 for the U.S. This fact goes to show that even though death rate is a broad statistic, at least it can show that the fear of severe and dire consequences of GMOs are not supported.

# CHAPTER 5

## Common Misconceptions of GMOs and an Analysis of Their Validity

In the debate about GMOs there are several research experiments and their findings that have been cited so many times, by those who argue against the use of GMOs, that they might as well be considered the most important evidence outlining the cons of GMOs. One of the most commonly used arguments against GMOs are that they might be unsafe for human consumption because DNA fragments from the GMOs could be transferred to the human body (Spisak et al., 2013). Another one is that GMOs have unintended side effects on the human body and specifically GMOs have been linked to cancer in a very famous rat study. The last major attack against GMOs is that they could potentially cause birth defects and developmental issues, such as autism, diabetes and Alzheimer's (Katiraee 2015). This section of the paper will tackle each of these arguments, by providing the hypothesis, the methods, and the research findings of the three research teams responsible for them and a careful look and analysis will be provided of their arguments, with an aim to find flaws and criticisms.

A research article titled "Complete Genes May Pass from Food to Human Blood" by Sandor Spisak and his research team describes GMOs as unsafe because they found foreign DNA fragments in the bloodstream of human participants. Specifically, Spisak and his team analyzed 1000 human samples from four independent studies and found that whole gene fragments from plant GMOs can be transferred to humans via the bloodstream. This research team used cfDNA, a type of plant DNA not found in humans, as a measure of how much transfer occurred between genetically modified food and the human body. (Spisák et al., 2013). This article has been viewed 940,269 times and cited 15,000 times. The human body is separated from the outside environment, and all of the organ systems, including the circulatory system are

designed to be separate from the external environment and conditions. Spisak's findings attempt to demonstrate that GMOs from the environment get access to human bodies, via the circulatory system and that is shown by the higher numbers of cfDNA, which is a plant DNA and not found in humans. However, before anyone questions the validity of this argument, it is important to say that Spisak and team never mentioned anything about this foreign DNA being integrated into our own DNA or genome. Even though cfDNA is found in human bloodstream, it is simply floating around there and not becoming merged into our DNA or becoming a part of our genetic material. But that same statement applies to any food one can imagine. When a human eats a strawberry or a salmon, their DNA is also transferred to our bodies, including many proteins, carbohydrates, lipids and other sources of nutrients that serve as energy fueling our bodies. The same fate awaits all molecules- to be digested by the various enzymes and breakdown pathways of the body, be absorbed by the bloodstream and transported to various parts of the boy where they are needed, and the excess is excreted (Gold 2013). GMOs behave no different than any other type of foods, organic or not. This paper is so famous in the debate against GMOs because when most people hear that particles from GMOs can be transferred to the human body they begin to worry and label GMOs as unsafe, but this is not their fault. Spisak and his team wrote a very biased paper forgetting to mention that the same thing happens when a human eats anything and simply the fact that those are GMOs does not tell us anything about safety or give causes for worry. However, perhaps the paper's biggest flaw is the fact that the experiment does not include a negative control. An example of a negative control would be selecting any non-GMO food particle and observing whether or not it can be traced and found in the bloodstream. The fact that there is no such control in Spisak's experiment is a major criticism to his paper because in science, controls are extremely important and almost every scientific experiment contains one.

Spisak's findings of fragments of DNA could be as a result of anything, including reagents or other contaminants from the environment.

The next misconception about GMOs is that they cause tumors and or cancers. The paper is written by Gilles Eric Séralini, who is a professor at the University of Caen and also the founding director of an anti-GMO research group, named CRIIGEN. This study, which links GMOs to tumors, is the most popularly cited paper against GMOs and as a result of it an indefinite ban on all GMO crops was issued in Russia and 28 African countries, while the French government began pressing for a ban of GMOs on the European continent (Edwards 2015; Hunt et al., 2012). This paper was tremendously effective in labeling GMOs as dangerous and it made many people's minds against trusting and using GMOs. So what was Séralini's methods and design of the study and also what did he find?

Séralini's paper was titled "Long-term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize" and was written back in September 2012 in Food and Chemical Toxicity. In his experimental design Séralini used only 20 rats and fed them on a strict three meals per day diet of GMO maize for 14 days. The diet contained 180% of the recommended daily nutritional values for maize that rats required. In the results, Séralini shows rats which developed large tumors on various parts of their bodies (Séralini et al., 2012). However, there are a few things that need to be considered before one concludes anything about GMOs.

First and foremost, Séralini's paper was not peer reviewed and eventually as a result of multiple shortcomings and harsh criticism from the global science community, it was retracted and Séralini, after refusing to do so voluntarily, was forced to republish his findings. In the republished paper Séralini explained his choice of rats and was much more careful with his word

choice and did not arrive to conclusions about GMOs' safety without accompanying data to back his claim. In the original paper, Séralini used rats in his study that were already predisposed to developing tumors and data reports show that some of the rats had a higher tumor incidence than others. Séralini also used very few rats for the study, thus not performing statistical analyses. Due to this, his findings are not statistically significant, because it is unclear whether or not the rats developed tumors as a result of the food or simply because they were predisposed to developing them. There was no control for the total amount of food consumed and feeding any organism with more than the recommended daily values will result in negative effects. One example of this is vitamin C and consuming lots of vitamin C on a daily basis leads to kidney stones in humans. Everything must be done by physiologically relevant method, and what Séralini did to those rats was far from that, in fact many scientists have called the study a "statistical fishing trip," "cherry picking of data," and "atypical" (Casassus 2015). Moreover, Séralini's experiment lasted a very short period, only two weeks, and there have been multiple long-term studies involving GMOs with results contrary to Séralini's. Other long-term studies, had shown no health issues with GMO foods. The Japanese Department of Environmental Health and Toxicology released a 52-week feeding study of GM soybeans in 2007, finding "no apparent adverse effect in rats." and in 2012, a team of scientists at the University of Nottingham School of Biosciences released a review of 12 long-term studies (up to two years) and 12 multi-generational studies (up to 5 generations) of GM foods in the same journal that published the Séralini paper, concluding there is no evidence of health hazards (Katiraee 2015). All of these long-term studies are great examples of the safety of GMOs and a proof that Séralini wrote an extremely flawed and biased paper that provides incorrect scientific information.

The last, most common myth about GMOs is that they are the cause for most of modern-day conditions and diseases of the Western world, including autism, diabetes, and Alzheimer's disease. The paper that is associated most with this claim is by Anthony Samsel and Stephanie Seneff who titled their study "Glyphosate's Suppression of Cytochrome P450 Enzymes and Amino Acid Biosynthesis by the Gut Microbiome: Pathways to Modern Diseases." It was written by American scientists and published on 18th of April 2013. In their experiment, the researchers used glyphosate, which is the active ingredient in Roundup- the most popular and most used herbicide in the world (Samsel et al., 2013). In their paper, the authors claim that the industry and many other scientists and researchers have stated and assured the safety of glyphosate, but the authors of the study argue otherwise. They state that the inhibition of glyphosate on P450 cytochrome is often overlooked and its toxicity is what is responsible for the majority of modern-day Western diseases. According to the authors, glyphosate enhances the damaging properties of food borne pathogens and environmental toxins. The paper specifically talks about the effects glyphosate has on humans, for several aromatic amino acids, including tryptophan, and tyrosine, phenylalanine. In addition, authors also argue that glyphosate leads to disruptions and interferences with sulfate transport.

It is important to know that this paper was not an actual experiment as the authors did not perform any research, but simply suggested a hypothesis in the form of a health claim that other research teams might find intriguing and perform an actual experiment and get associated data to prove this claim. Moreover, the paper was published in a predatory journal, or a pay-for-play journal, meaning that one can publish anything as long as they pay a minimum fee. As one can already tell, such journal websites are have very negative consequences for science as incorrect and wrong information could be provided to people,who not knowing about predatory journal

websites, will believe this information simply because it written by scientists. This paper was reviewed and critiqued by many scientists, researchers, and Keith Kloor, who is a science journalist for Discover Magazine compared Samsel and Seneff's paper to a chalkboard drawing, because of its lack of depth and necessary detail specifics (Katiraee 2015).

As one can easily see, all of these arguments against GMOs are huge misconceptions and the papers that present them are very far from the truth about GMOs and genetic engineering as a whole. What these myths are effective in doing, however, is scare people away from GMOs. Despite, the fact that scientists could break down and explain the multiple flaws that the papers contain and provide criticisms, including the wrong information and poor word choice, the bad has already been done and many people will always associate GMOs with cancer, autism, and other unwanted conditions. Similar thing happened with what is known as the vaccine scare and people nowadays will refuse to get their children vaccinated due to fears that vaccinations may develop autism. This false myth was a result of a statement, which is completely wrong and made by a scientists who falsified data and caused a series of bad consequences as a result (Rao 2011).

## Conclusion

Two of the most serious issues that humanity faces are overpopulation and malnutrition. With the increasing number of people around the globe, the need for resources increases as well and access to necessary resources becomes more difficult. Even with the present number of human population there are millions of starving men, women, and children who are not only malnourished but in serious trouble of getting access to water and food. These are important issues that require the highest level of attention and a careful course of action must be undertaken. One possible solution is genetically engineered organisms and GMOs are not new and have been government approved for decades in the United States. Moreover, certain types of GMOs may open new doors for the human race in its need to support its ever growing population. Such are the types GMOs that increase nutritional yield and provide more nutrients for the same price, weight, and amount. The two specific examples of nutritionally enhanced GMOs discussed are Golden rice and the GMO legumes peas and soybeans. The first one is a humanitarian project aimed at helping the millions of individuals suffering from vitamin A deficiency resulting in irreversible blindness, while the latter have enhanced amino acid content and lower production cost.

The beneficial applications of GMOs are many, however, there is a huge debate regarding their safety for both humans and the environment. This debate and those arguing against GMOs stall the worldwide implementation of GMOs and thus fail to prevent addressing the overpopulation and malnutrition issues. However, it is the 21st century and in 2015 no individual deserves to be denied a fundamental human right such as healthy life. Many people who are neither supporters nor opposers of GMOs in the debate believe that until there is a working solution that could more adequately tackle dietary issues around the world, such as

malnutrition or starvation, like vitamin A deficiency in Asia and Africa, there is simply not a better way to help individuals than GMOs. Not only do they have tremendous promise in enhancing nutrition but they also have many economic and social applications, all of which have a positive effect on developing countries. After all, it is easier to bash at an idea that one does not find ethical, moral or even good, than it is to actually sit down and find a solution to the issue at hand. So until a better solution is discovered and agreed upon, Golden rice, GMO legumes, and other nutritionally enhancing GMOs are all that men, women, and children of many countries have.

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