SENIOR THESIS

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Using Genetic Engineering to Combat World Hunger

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Introduction

Inside each plant, there lies a blue print. This blue print, or genome, contains millions of possible variations, which could lead to a healthy, hearty plant or one prone to infections and diseases. Through advances in sciences and technology, the genome can be transformed to create plants that can weather drought and diseases better than ever before. These changes in plants can lead to easing, and potentially alleviating, the suffering of the millions of undernourished people across our planet.

The population of the world is steadily increasing and in order to feed every person, the rate of food production must be comparable. Unfortunately, crop production is growing, but not fast enough in the areas that could benefit from it the most. This leaves many nations’ populations malnourished and suffering. Traditional methods of agriculture can no longer provide the people of the world with enough food to sustain themselves. Poverty is one of the root causes of hunger because without the funds to support agriculture, people will starve. In a report by the World Hunger Education Service, the largest concentration of people in poverty is in Sub-Saharan Africa and South Asia\(^1\). These are the two locations in the world where the greatest number of people go hungry every day.

To counteract world hunger, the nations of the world must undergo policy and economic changes. The introduction of regulated commercialized farming coupled with the recent scientific advances of genetic engineering will help increase the quantity and quality of crops consumed by those in these areas of extreme poverty and hunger. This discussion focuses upon the benefits of adopting certain
selective methods of genetic modification to increase food quality and production. Although the affects of genetically engineering a plant can include alterations that make it possible for plants to produce antibiotics, phytochemicals, even vitamins and minerals not found naturally in the species, these issues will not be discussed\(^1\). It is important to first make the initial ground work for the acceptance of thoroughly research genetic modification before more radical methods can be explored. This paper will explore the benefits nations throughout the world would experience if genetic engineering, coupled with economic and policy changes, were implemented.

**History of Genetics**

The study of selective breeding is not a new trend to farming today; it’s a practice that has been around for several generations. Due to the work of numerous pioneering scientists, scientific breakthroughs have allowed farmers in the present day to cultivate heartier crops more so than ever before. One of the first innovative scientists was Gregor Mendel. Mendel was born in 1822 in Bruin, Moravia to farmers Anton and Rosine Mendel\(^2\). Mendel attended the University of Vienna where he studied mathematics and science to become a teacher. Although he was an intelligent young man, Mendel’s family had difficulty in affording further education so in order for him to continue, he entered the Augustinian order. At the monastery in Brno, Mendel began to teach high school students as in addition to researching botany and, what we would commonly referee to today as, genetics\(^3\).
In Mendel’s original study, he took an atypical variety of a plant found in the monastery and planted it next to a typical plant of the same species. He grew the progeny, or the sequential generations of plants, side by side to see what traits each would express. It was previously hypothesized that the traits organisms expressed were acquired throughout their lifetime in response to the environment and that these traits would pass on to their offspring. Mendel however, helped to refute this theory through his research; he found that the progeny expressed the essential traits of their parent plant and were not affected by the environment. This spurred Mendel on to further his research upon mice and pea plants.

In 1866, Gregor Mendel’s research was published by the Association for Natural Research in Verhandlungen des naturforschenden Vereines in Brünn (Transactions of the Brunn Natural History Society) under the title “Versuche über Pflanzen-Hybride” (“Experiments in Plant Hybridization”) after he presented his findings at the meetings of the Association for Natural Research in Brno on February 8th and March 8th, 1865. Unfortunately, Mendel’s revolutionary research was met with a lack of enthusiasm and understanding because he was the first to use math and statistics to analyze biology.

Mendel’s research had begun in 1856 where he pollinated pea plants and saved the resulting seeds to be planted in order to observe the traits of their progeny. He then self-pollinated the subsequent generations until the resulting plants bred true for certain physical characteristics to create “true-breeders.” Once Mendel obtained true-breeding lines, he carefully cross bred the breeds together.
creating various hybrid plants. Keeping careful records of each pea plant and the offspring it produced, Mendel noted the various resulting physical characteristics. Some of the characteristics Mendel observed were: color of the flower, height of the plant, texture and color of the peas plus color of the pea pods\(^2\). He noted that by crossbreeding the true-breeder pea plants, a distinct three to one ratio was evident in the subsequent offspring. This ratio indicated that roughly three fourths of the offspring displayed one trait, such as round peas, while the remaining one fourth displayed the second trait, wrinkled peas\(^2\).

The discovery of this ratio gave rise to the theory of dominant and recessive traits in organisms. It also indicated that these traits were passed on individually and intact from parent to progeny, illustrating that the traits did not blend as had been previously theorized. Under the blending theory of inheritance, offspring were a blend or mix of their parents which would eventually lead to the elimination of variations in species over time. Mendel’s research however disproved the blending theory because ratios, and therefore variations, were maintained over seven years of research\(^3\). He concluded that the parental generation transfers half of its hereditary information to each of the progeny, with each of the progeny receiving a different set of hereditary information, referred to as the plant’s genotype. Additionally, the different physical traits expressed by the progeny, called the organism’s phenotype, were not linked nor did they combine; they were inherited as separate discrete traits.
Although this research was not initially received well, Mendel work was finally recognized in 1900 by three European botanists working independently of each other. Carl Correns of Germany, Hugo DeVries of the Netherlands, and Erich von Tschemar of Austria had been separately researching hybridization of plants. When the three went to publish their findings, they found that the conclusions they arrived at from their research about the laws of inheritance had been discovered thirty-four years earlier by Gregor Mendel. They were able to then substantiate their findings from the work Mendel has previously done, which is now referred to as Mendelian genetics. The abstract ideas of Mendelian genetics were attached to concrete ideas through of the findings of Friedrich Miescher and Walter Flemming. In 1869, Miescher isolated a phosphorous rich substance from white blood cells which he called nuclein, which we know today to be deoxyribonucleic acid or DNA. Later, in 1879, Flemming observed and recorded the full process cell division or mitosis in a salamander. Flemming described the behavior of the DNA molecules or chromosomes of the cell during this process.

In 1902, Walter Sutton studied furthered research on cell division, observing the process that created sperm and egg cells called meiosis. In Flemming’s study, two chromosomes of each type were present in the cell after undergoing cell division. In Sutton’s research however, the studied grasshopper cells had only one chromosome of each type. When comparing the chromosomal patterns observed during the process of meiosis to that of Mendel’s hereditary ratios, there was a clear parallel between the two. Sutton’s research was further proof that the idea of half of
the genetic material or “genes,” as coined by Danish botanist Wilhelm Johannsen in 1909, were passed from each of the parents to each of their progeny.

To study how genes were passed from one generation to the next, *Drosophila melanogaster*, or the common fruit fly, was the organism of choice in the chromosomal studies performed by Thomas Hunt Morgan and his students at Columbia University in 1911. The fruit flies reproduced and matured rapidly which allowed for a more through study of changes in the sequential generations due to the high number of progeny produced. He and his students studied the presence of the linkage of genes in the flies, particularly sex linkage. They observed this phenomenon through studying flies with white eyes. Male flies were heterogametic, meaning the gametes or sperm they produced could carry the genetic information for female or male progeny. The observed the phenotype of the progeny and statistically analyzed how this related back to the phenotype of the parents. This illustrated that the chromosomes were what carried genes and that the genes were in a linear sequence along the chromosome. Spontaneous mutation was also a factor that was frequently observed in the generations of flies. This research was published in Morgan’s book, *Mechanism of Mendelian Heredity* in 1915, giving future scientists further insight into the complexities of heredity.

Until the discovery of DNA’s importance by Oswald Avery, Colin MacLeod, and Maclyn McCarty in 1944, DNA was believed to be simply structural components of cells. Proteins were thought to be the component that transferred genetic information due to their high complexity and variety. In their research,
Avery, MacLeod and McCarty injected mice with strands of R (rough, non-virulent) and S (smooth, virulent) Streptococci and observed the affects it had upon the mice. When heat killed S strain cells were injected along with R strain cells, the mice developed pneumonia and died because of the live, virulent S strain cells found in the mice’s blood. In order to identify what part of the bacteria was causing the R strain to transform into the virulent S strain, different methods of analysis were used to eliminate various possibilities. Since the transforming principle could be precipitated with alcohol, it could not be a carbohydrate \(^4\). The enzymes proteases, lipases and ribonucleases were used to digest proteins, lipids and RNA respectively. Since this step did not prevent the R strain from being transformed into the virulent S strain when exposed to the heat-killed S strain, proteins, lipids and RNA were not what transferred the genetic information \(^4\). However, it was identified that the transforming principle was rich in nucleic acids and had a high molecular weight. This lead to the discovery of DNA: the molecule which passed on the heritable changes in bacteria\(^4\). This discovery was later verified by work done by Alfred Hershey and Martha Chase in 1952 on bacteriophage T4 \(^4\).

In 1972 at UC San Francisco and Stanford, restriction enzymes were used to cut DNA in one species at specific locations and then fuse the cut strands back together after insertion into a host cell, which was often bacterium. This research led to the production of the first recombinant DNA molecules \(^4\). Using this genetic recombination technology, the first genetically modified food, the FLAVAR SAVAR tomato, was created in 1994. This modification to the tomato allowed it to stay
firmer for a longer period of time, increasing of time the tomato could be left on the vine before being shipped. The sale of this fruit was approved by the FDA since it was deemed as safe as traditionally grown tomatoes and no additional labeling was required since the modification was so minute.

The sequencing of the genome of various organisms became a point of great interest. In order to come to a full understanding of how and what modification may do, scientists sequenced *Arabidopsis thaliana* in 2000. An international group of researchers, working on the *Arabidopsis* Genome Initiative, selected this plant because it contained very little junk, on non-coding, DNA with an estimated total of 25,000 genes. This plant helped pave the way for the sequencing of crop plants, since *Arabidopsis* was of the mustard family. In 2002, two subspecies of rice were analyzed and their genomes were sequenced. The estimation of the genome of rice contained 43,000 to 63,000 genes, but this was finally lowered to a final number of about 38,000 genes. Since rice is one of the main food stables of the planet, modification of this crop giving it more desirable traits would help world populations. These advances in genetics could then be applied to the other important crops of the world such as wheat and maize.

**Farming Methods**

Since the move from a nomadic hunting culture to a settled agricultural one, mankind has been breeding and cultivating plants in order to achieve the best crop output. Farming methods have changed and developed over time as different
techniques were found to increase the food gathered at harvest time. Today, traditional methods such as growing one crop alone to support pollination in addition to new scientific methods, such as genetically modifying food, can be seen around the globe. With each of these methods however, come both benefits and drawbacks.

*Conventional Methods*

For over 12,000 years, farmers have been saving the seeds from useful plants and using them to grow them under more desirable conditions and locations. Because of this, natural changes or mutations have occurred over time creating a large gap between the wild and cultivated species of plants. Since Mendel's research in the mid nineteenth century, the laws of genetic inheritance he discovered gave scientific basis for breeding plants. Using conventional breeding techniques, or simple manipulation the chromosomes of a plant to achieve certain desired traits, was the first step in more modern methods of farming.

Three main methods of conventional breeding exist: pure line selection, hybridization, polyploidy and mutation. In the first method of breeding, a crop of plants exhibiting a desired trait are breed amongst themselves to cultivate the production of further generations that would exhibit the desired trait. The progeny are grown from the plants selected to observe which plants exhibit the desired trait. The progeny expressing that trait are then inbred for several generations to verify that the plants selected will continue to produce progeny expressing this trait under
various conditions. The final selected plants are then used to cultivate plants that will reliably exhibit the desired trait.

The second method of farming involves cross breeding plants to create hybrids. Mendel’s research in 1856 made use of these techniques and led him to the discovery of the laws of Mendelian genetics. Farmers breed different plants together to include different traits from the parental generation, in hopes of transferring desirable traits to the progeny creating a hybrid plant. To create a hybrid, plants are cross-pollinated from homozygous or purebred plants. Homozygous plants are produced from the self pollination of a plant’s female flower by its own the male flower. The purebred lines are breed or “outcrossed” with other purebred lines to create hybrids, just as Mendel had done with his pea plants. In addition, wild plants that exhibit traits beneficial to the crop can also be crossbred with the cultivated plants to create a new hybrid. The progeny produced by cross breeding will inevitably produce a large number of undesired traits along with the desired trait. In order to eliminate the undesirable traits, back crossing, or repeated crossing with the crop parent, is done to create more desirable offspring. The hybrids produced can fall into two main categories: interspecific and intergeneric hybrids. Interspecific hybrids are created by crossing different species within the same genus while intergeneric hybrids are created by crossing species of different genera together. One example of successful hybridization is heterosis where the plant expresses increased vigor. When a plant is inbreed, the resulting progeny’s vigor and size are greatly reduced in subsequent generations until this reduction
levels off after the sixth or seventh generation. When these plants are breed with another inbred variety of plant, extreme vigor and an increase in the size of the plant and fruit can be observed and is referred to as heterosis. In 1919, the first commercial hybrid maize was created in the U.S. for human consumption. The downfall of this method is that the increased affects seen in the first hybridized generation are lost on subsequent generations; therefore, farmers today must purchase new hybridized corn seeds each season to ensure robust crop production.

This method of crossbreeding takes time creating thousands of undesired plants and with the growing population of the world, methods that are much more selective a less time consuming are being researched.

The polyploidy method of crop production is the practice of using or inducing a plant to possess three or more complete sets of chromosomes. A plant containing two full sets of chromosomes is called diploid while a polyploidy plant possesses three or more. A plant can be stimulated to create an additional set of chromosomes by applying the chemical colchicine. These plants have greater genetic variability and size because of the extra sets of chromosomes but it also causes the plant to develop at a much slower rate and decrease their fertility.

Each of these methods rely on cross breeding of plants to create a crop better suited to handle climate changes, weather conditions, even pests, all the while producing better grains, fruits and vegetables. These methods are time consuming however, and many variations in the progeny make it difficult, but not impossible,
to produce desired plants. For this reason, science has relatively recently begun using knowledge of DNA to accelerate this breeding process.

*Genetic Modification*

Genetic engineering is a relatively new science, with the first direct mutation of the genome in 1972 through the use of recombinant DNA molecules. Genetic engineering includes either the manipulation of the sequence of an organism’s genome or the transfer of genes from one organism to another. There are many different methods dealing with genetic selection but the methods focused upon here are marker-assisted selection, specifically restriction fragment length polymorphism, and induced nuclear mutation. Each of these methods directly transforms the genome of the organism without the tedious process associated with traditional methods of farming mentioned in the previous section. Although there are many methods to genetically engineer plants, one of the recently emerging methods is called marker-assisted selection (MAS). In order to comprehend the complexities of this method, one must first have a general understanding of genome of living creatures.

The blueprint of many organisms on Earth is DNA, or deoxyribonucleic acid. DNA is a double stranded helical structure composed of many units called nucleotides. Each of the nucleotides in the DNA strand consist of a five carbon sugar called deoxyribose bonded to a phosphate group. Attached to this sugar phosphate backbone is a nitrogenous base which would be one of the following: adenine (A), guanine (G), cytosine (C), or thymine (T). Each of the bases in one
strand bonds to its complimentary base (A to T and C to G) in the second strand to link the two strands of DNA into the one double helical structure. The DNA is then wound into a compacted form called a chromosome. The number of chromosomes present in any given organism varies from specie to specie. The genome of an organism is then the full set of chromosomes present in the cell of an organism.

In the process of MAS, certain portions of the genome, referred to as a molecular marker, is used to identify the location of a particular gene of interest and the relation between the marker and gene of interest is determined by using a DNA assay. The gene of interest is a specific recognized sequence of nucleotide bases in the organism’s genotype. These bases then act as a blueprint for the construction of a protein and it is these proteins that are the cause for the expression of the genes as seen in the organism’s phenotype. It is the study of the phenotype of the organism along with the determination of the allele, or gene variant, present in the organism that makes MAS possible.

The genome of every organism contains a portion that encode for proteins but the larger segment of the genome is referred to as “junk DNA” or DNA that does not encode for proteins. The exact purpose and function for this portion of the genome is still unknown. It is in this segment of non-coding DNA that many of the molecular markers, or identifiable sequence of DNA, are found; however, some are found nearby or within the genes of interest themselves. The MAS method then uses these identifiable markers to select a non-identifiable allele, making sure that the
selected variant of the marker present in the genome produces offspring expressing the desired trait.

The relationship between the marker and the gene of interest falls into three main categories. The first is when the marker is located within the gene of interest. Secondly, when the gene and marker are in disequilibrium (LD) throughout the population and are physically very close to each other. The final category is when the marker and gene are in equilibrium (LE) throughout the whole population. It is this final category that is the most difficult to use in MAS. In order to make sense of the relationship of these markers to the genes of interest, molecular marker maps have been constructed for many of the major crops throughout the globe. This has created a framework for the process of MAS. Each map is different with the density of each varying from species to species.

The most widely used method of marker-assisted selection is called Restriction Fragment Length Polymorphism (RFLP). In the RFLP method, enzymes called restriction endonucleases, cut the DNA at specific recognized nucleotide sequences. Each restriction endonuclease recognizes a separate sequence of bases in the DNA strand, enabling scientists to use these enzymes to isolate a gene of interest.

Once the plant has been exposed to the endonuclease, the DNA of the plant is segmented into fragments of varying lengths depending on where the DNA strand was cut according to the number or recognition sites present in the genome. It is important to note that no two genomes are the same even within a species due to
mutations the organism undergoes. The number and length of DNA fragments will differ, which has lead to the term of restriction fragment length polymorphism (RFLP). By using a process called gel electrophoresis, the DNA fragments can be separated according to their size with the larger particles remaining towards the top of the gel and the smaller fragments moving towards the bottom. In order to see the banded separation, the DNA fragments are hybridized with radiolabeled or fluorescent DNA probes. When comparing the banding patterns observed in two organisms, the closer the organisms are related, the more overlapping of bands will occur. Breeders can also identify if a plant has the trait of interest by observing if a specific band is present in the gel. The endonuclease chosen would recognize a particular nucleotide sequence that lay close to or even within the desired gene and the resulting band would indicate the presence of the desired gene. This process allows breeders to identify whether a plant has the trait of interest to avoid the unnecessary process of cross breeding followed by back breeding.

After using RFLP to identify the presence of a gene within a plant, breeders can use a more invasive procedure called gene transfer. Due to sexual incompatibility to other lines of a crop or with its wild relatives, a plant is naturally limited to a specific pool of available genes and traits. Using the genetic engineering method of gene transfer, genes that would not normally be available to a plant can be inserted into the genome of a plant. This process would insert genes from the plants own species or from other organisms which could include anything from bacteria and fungi to other plants and animals resulting in a transgenic
plants. Using gene transfer, the transgenes are inserted into the nuclear genome of a plant cell. The two main processes to create these transgenic plants are called Agrobacterium-mediated DNA-transfer and direct DNA-transfer, with the former being the more commonly used method.

In the method of Agrobacterium-mediated DNA-transfer, the natural behavior of the bacterial plant pathogens of the genus Agrobacterium is used to transfer genes into the plant’s genome. This species of bacteria insert their genes into the host plant's genome, and when used in their natural state, they cause diseases in the plants. The two bacteria commonly used from this species are Agrobacterium tumefaciens and Agrobacterium rhizogenes. Both species contain large circular molecule of DNA called plasmids and the portion of the plasmid inserted into the host organism is called T-DNA. In nature, the T-DNA penetrates the nucleus of the plant cell and inserts itself randomly into its genome to be inherited by the plant's progeny like any other plant gene. The bacterial genes will then cause a change in the host plant to create new genomic expressions such as tumors. When the Agrobacterium are used in genetic engineering, the gene within the T-DNA that induces the tumors in the host plant is removed using an endonuclease and replaced with foreign genes from other organisms such as plants, bacteria or animals. The foreign genes are then inserted into the host's genome as the tumor inducing genes in the T-DNA of the Agrobacterium had done in nature. This process is highly successful but only to plants that are susceptible to Agrobacterium. Plants such as legumes and monocotyledons like cereals do not
respond positively to Agrobacterium-mediated transformation so this method of direct DNA-transfer is not commonly used for these crops. Direct DNA-transfer includes two processes: particle bombardment, electroporation and polyethylenglycol permeabilisation. “Particle bombardment, often referred to as biolistic transformation, uses small tungsten or gold particles with active DNA segments attached to it, to then accelerate them into a plant’s tissue at high velocity.” These particles pass through the plants cell wall and are lodged inside the cell where the DNA can then be incorporated into the plant’s genome. This process is used on several species, especially in the case of cereal crops; It has also been successfully used on the seeds, embryos or meristems of plants such as rice, wheat, soybean and maize.

The second method direct DNA-transfer, electroporation and polyethylenglycol permeabilisation, is a less functional form of genetic engineering. Electroporation uses electricity to inject the transgenic DNA into the host cell’s genome. Short pulses of electricity cause the otherwise impermeable plasma membrane to become permeable for a short period of time allowing the DNA to pass through. Protoplasts or plants without cell walls are constructed in order to allow the diffusion of the transgenic constructs. The protoplasts can also be taken up into the host’s cells using phosphate or calcium/ polyethylenglycol (PEG). Both processes are difficult however, because forming a complete plant from protoplasts is rare in most species of plants.
Even with these two methods, the addition of foreign genes or transgenes into the genome of the host plant is useless if the genes are not expressed. This expression is a result of the DNA being transcribed into mRNA, or messenger ribonucleic acid, which is then translated into a protein. It is these proteins that exhibit and carry out the functions of the transgenes. In order to indicate which nucleotide sequence is the sequence to be expressed for a desired gene, a promoter lies “upstream” from the desired sequence. The promoter is the sequence of nucleic acids before the sequence of gene-expressing nucleic acids that allows RNA polymerase bind to the DNA strand. This polymerase is an enzyme that synthesizes the mRNA transcript from the DNA template strand. The promoter also defines how the gene is expressed in the plant. It determines under which conditions and to what degree the gene will be expressed. Similar to how specific endonucleases can be, promoters can be specific with gene expression. Sometimes it is preferable to express the transgenes in certain tissues, to a certain degree or at a certain time. The promoters aids in this selective expression. One specific promoter is the promoter of the 35S gene in the cauliflower mosaic virus. This promoter causes an elevated level of expression of transgenes in most cells of the host plants that have been tested.

Expression of the transgenes is not completely under control even with the use of promoters and restrictions endonucleases however. Even when the foreign DNA is inserted into the genome of the host organism, the location at which it is inserted is random. Because of this, different insertion sites will have varying
affects upon the expression of the transgenes, either increasing the expression of the gene or minimizing it. Even with using promoters and different methods of exogenous insertion, the level of expression cannot be wholly determined.

Once the transgenes have been incorporated into the host cell's genome, a careful selection process occurs to identify and isolate the cells in the organisms that have incorporated the desired trait. This is difficult because the number of cells in the host organism that have been altered is generally much smaller in proportion to the number of cells that have not been altered. To select these cells, the genes coding for the desired trait are bonded to a gene, referred to as a marker gene that readily allows for the selection of transformed cells. Cells that contain the marker gene now have the ability to grow in the presence of a selective agent, specifically compounds such as herbicides and antibiotics. In the case of the marker genes that protect the cell from antibiotics, one of the most common gene is the aminoglycoside-3′ phosphotransferase gene (APH(3′)II). This gene codes for the production of an enzyme that inactivates the antibiotics, such as kanamycin, neomycin and G418 through phosphorylation. In the case of the markers that encode for an herbicide resistance gene, this has been obtained through the incorporation and expression of a gene that detoxifies the herbicide or creates a product that will behave like the target of the herbicide without being affected.

In order for farmers to get rid of the weeds that are interspersed throughout the crop, herbicides that are relatively selective must be used so they do not damage the crop. However, if this herbicide resistance gene is incorporated into the genome
of the plant, farmers can use a more general type of herbicide and do not have to worry about the crop being affected by the herbicide used. Weeds, on the other hand, can be gotten rid of with greater ease now because of that.

Even with these varying methods, the rate at which a plant can regenerate varies from specie to specie. The majority of time creating a viable crop containing a transgene slowed because it is still difficult to generate a plant from protoplasts, cells and other plant tissue \(^7\).

As an alternative to the aforementioned genetic engineering methods, the production of nuclear foods using methods such as radiation has become another viable method of genetic modification. Rather then alter the genome of the organism by splicing it apart and inserting other genes into it like genetic engineering, using radiation can mutate the genes of the organism to produce a plant with more desirable traits according to the International Atomic Energy Agency (IAEA) \(^9\). This method has been in use since the 1920’s and is referred to as mutation induction \(^9\). This method is cost effective producing crops that can better adapt to harsh conditions such as drought and grow resistant to pest and diseases.

In the ninety years radiation has been used to produce mutations in plant genomes, 3,000 crop varieties of 170 different plant species have undergone mutation induction by the IAEA \(^9\). Some of the successful crops that have been cultivated using this method include barley plants that can now successfully grow and reproduce at an altitude of 5,000 feet and rice that can grown in saline soil \(^9\). The genome for these plants and the other 3,000 are genetically altered through the
use of mutagens. As explained before, the genome of a plant can have certain desirable traits already encoded within its genetic code but it is not expressed, or expressed to its greatest degree. Using mutagens such as gamma rays or chemicals, the plant undergoes a process called induced mutation to transform its genome. These mutations come from the genome of the plant itself, not from the induction of foreign DNA like genetic modification. Once the plant has been exposed to the mutagen, such as radiation, the plant’s DNA is mutated at one location, creating progeny that differ from the parental generation while leaving no traces of residual radiation. Many mutated progeny are produced however to see whether the desired trait is present in those plants; the plants that exhibit the desired trait are sent to breeders to then be crossbred into a crop to pass on the induced mutation. This part of the process is similar to conventional methods of farming mentioned before, but the lengthy backcrossing crossing that is common to acquire a crop that consistently demonstrates the desired trait is not required.

Over the centuries, plants have become less and less varied due to some conventional farming methods like backcrossing because variations are bred out of the plants. Although some variants are variables that are undesirable to the final crop, some variants can insure survival of the species. If a species is too genetically similar, a single pest or disease could potentially eradicate the crop, possibly even the whole species. Through the method of radiation induced mutations however, millions of variants are created allowing for enhanced crop survival. This method then requires breeders to observe the progeny for the desired traits after being
crossbred. The benefit is the increase speed in which desired results occur in comparison to conventional methods. This method of induced mutation creates crops that have a reduced dependency upon pesticides in addition to the induced variation. Not only is this method less costly, it helps reduce the impact it has upon the environment. The improvements provided by the reduced use of pesticides will be discussed at greater length in the next sections.

Many third world countries are not capable of creating the facilities that allow for the induced mutation method as seen here in the United States and other industrialized nations. This however does not limit this technology from being incorporated there. Nations that lack the technology and funding can send seeds from their crops to undergo the mutation process in another country. These seeds are then subjected to the mutagen and are sent back to their native home to be used to be breed, identified and then selected to create a final crop that carries and expresses the desired trait.

An important discovery to note in the uses of genetic engineering is experiments done on the Arabidopsis thaliana plant using the method of mutation induction. The Arabidopsis thaliana is a plant containing a small, simple genome that was relatively easy to map and sequence. This plant was used to observe whether it was possible to form the apomixis gene, a gene which allows a plant to set seed without fertilization, virtually creating a clone of the parent as a last resort to ensure the species’ survival.
The apomixis gene is a regulatory gene that switches on early in the sequence of genetic developmental events of the plant. In the experiment performed by Dr. Abed Chaudhury's and his team of researchers at CSIRO Plant Industry in September of 1997, Dr. Chaudhury’s team produced a mutant arabidopsis plant that brought them close to isolating the apomixis gene \(^{10}\). In a normal plant, the silique, or the small pod-like structure that stores and protects a seed while it develops, is formed even when unpollinated, although it is relatively small. In their experiment, a sterile male mutant Arabidopsis was pollinated using pollen from a normal plant to get an F1 generation \(^{10}\). The seeds of the F1 generation were then exposed to a mutagen called ethyl methyl sulfate to produce an F2 generation \(^{10}\). In the F2 generation, one plant went part way to producing a seed without being fertilized, an indication that they had partially turned on the apomixis gene creating a partially apomictic plant. They identified the gene that controlled the initial steps of silique formation and seed development which was named FIS2 (Fertilization-independent Seed 2) \(^{10}\). Although this gene is not the apomixis regulatory gene, it is a gene that is probably regulated by apomixis \(^{10}\). It is important to note that by using this method, a plant that possesses the traits desired could be reproduced repeatedly creating a fixed hybridized crop ensuring their genetic integrity.
Pros and Cons of Scientific Advances

With each of the aforementioned methods, there are benefits and deterrents that must be taken into account. Although these issues may seem to be the solution to the increasing issue of world hunger, the science behind each of these methods must be analyzed to see what problems may arise and if they could cause a greater problem than the food shortage that already ravages many parts of the world today.

Genetic engineering and genetically modified foods, often referred to as GM foods, can help reverse the affects of a lack of proper nutrition in a portion of the world’s population today. In the method of genetic engineering discussed earlier, specifically that of marker-assisted selection, particular traits can be tested as in the seeds of plants without having to plant them and grow to a mature plant to observe its phenotype. The genotype of the plant can be used to determine whether the plant will express the gene and avoid years of potentially wasted time. The drawback to this method is the lack of through research done for genetic improvement in plants. It is difficult to identify and isolate genes of moderate to large effect at this point so attempting to manipulate complex genes that are regulated by several different molecular markers are yet to be undertaken.

From MAS, the use of restriction fragment length polymorphism (RFLP) allows for the incorporation of many genes that would produce plants better suited to harsh environments. Relying on the natural interaction of cells and bacteria, the RFLP method is in and of itself relatively natural. Bacteria has been invading cells of other organisms for thousands of years, incorporating their DNA into that of the
host organism so that the survival of the bacteria is ensured. The transgenes of the bacteria are encoded into protein and replicated as the host cell’s DNA undergoes replication. It is when an animal’s or other plant’s DNA is incorporated into the genome of a plant that the line of what is natural and unnatural begins to blur. The incorporation of transgenes is not fully predictable at this point so results can vary from what is projected.

Using particle bombardment is even less efficient than using bacteria as in the Agrobacterium-mediated transformation \(^7\). Although the particles are not cheap to produce, the method has been shown to hold a greater potential to the use of genetic manipulation. The disadvantage for the use of protoplasts in the electroporation method is the difficulty in creating full grown plants from the protoplasts or wall less cells \(^7\). If a successful method to transport the DNA containing the gene of interest across the reversibly permeable lipid bilayer of the cell was created, protoplasts would not have to be incorporated. This would then make this method a more viable means of genetic manipulation.

The nuclear method of genetic engineering seems to be a promising alternative to the traditional methods of genetic engineering plants. Using the radiation is a bit more predictable than the genetic engineering method of RFLP \(^9\). This method amplifies the genes already present in a plant in order to make the resulting crop stronger and better suited to survive harsh conditions. There is no insertion of foreign DNA so the plant remains relatively close to its natural state. This method however uses mutagens like radiation, which can cause the cost of the
process to be relatively expensive. However, in nations that have used it, it was found that the profits out weight the initial cost \(^9\). If residuals of radiation or other mutagens that were used could still be found in the plant, those mutagens could affect and transform the genome of the organisms that consumes it, including humans. The good thing however is that the radiation used does not reside in the plant tissue so there would not be residual affects caused by this alteration of the genome of the plant.

In the induced mutation experiments performed by Dr. Chaudhury and his team, once the apomixis gene is identified, this knowledge could be carried over and applied to one of the largest crops in the world, rice \(^{10}\). Rice hasn’t been hybridized like wheat and maize so the canvas is blank and ready to be worked upon. Although this would allow rice crops to become immune to cross breeding, thereby ensuring progeny with the desired trait, it could make the species more susceptible to disease and pests. The possibility of it being wiped out by a parasite, virus or bacteria is thereby increased. It would therefore be necessary to somehow incorporate some variation within the genome of each plant to ensure the plant is resistant to any such attacks.

Overall, the incorporation of science is an important stepping stool to increase the integrity, quality and yield of plants. Each method must be carefully evaluated for the benefits of incorporating a particular method into a crop. Do to the fact that radiation induced mutation allows for the use of a plants own genetic material while ensuring variation in the species, this seems to be one of the more
desirable methods to use. Although this method would still be more time consuming then the method discussed using the apomixis gene, using radiation could possibly allow for better mutations to arise in subsequent generations of the plant since the progeny would not be strictly a clone of its parent.

**Reluctance to the Application of Science**

Science is evolving at an incredibly rapid pace in comparison to the progression of the law. Legislation is having difficulty in keeping pace with recent scientific breakthroughs due to the long and arduous processes each decision must undergo. In conjunction with the slowly changing governmental policies, other factors weigh into the reluctance to readily adopt and support genetic modification into the food stock of the world. Some of these issues are grounded in legitimate concerns, specifically those concerned with the affects these modified crops will have upon the health of living organisms that consume them, however a lack of the general publics’ understanding of genetic engineering has overstated some issues. Many are anxious about the potential influence monopolies may have if genetic modification is adopted throughout the globe while other concerns are more focused on the economical and financial affects these crops will have upon domestic and the global economies.

Before adopting a new scientific process, much research must be done in order to observe any adverse affects that process may cause. In the case of genetic engineering, years of study have been done but the exact outcomes of the progeny of
the plant are never completely definitive. Due to this fact, unknown health concerns can rise from the unknown mutations that may occur when the genetic code of the plant is altered. Genes can be turned on or off, mutations can occur and cause the proteins being produced to have an allergenic affect. The US Food and Drug Administration (FDA) has therefore taken this issue into careful consideration when deeming a new plant safe for human consumption. Even with this knowledge, the FDA had not found acceptable methods to test for possible allergens due to gaps in their scientific knowledge in their 1992 Policy Statement. Banning these foods completely however, would prevent research in a field that holds great potential to helping third world countries nourish their population so the present solution is to require producers of GM foods to perform premarket test and precautions. It is also important to note that myths and misunderstands have magnified the potential health concerns which has affected the view many people have of genetic engineering. Specifically to the method of mutation induction discussed earlier, radiation is one of the mutagens used. Many people are concerned with the potential affects radiation may have on the organism that consumes it but this radiation process is different then simply irradiating foods. Food-irradiation can be used to reduce food borne illness, reduce food lost to insect and rodent infestation and can help eliminate the need for fumigation. It is a misconception that the process of food-irradiation is what mutation induction is since both involve radiation. It is important that the health concerns associated with both methods
however, are separated so the public opinion is not swayed due to misunderstandings.

Without regulation, corporations can become one large conglomerate, charging any amount for a product if they are the only producer. In the case of genetic engineering, many people fear farmers will become completely dependent upon the producers of genetically modified seeds. In a paper by Khadja Sharife, 60% of genetically modified seeds have been created in such a way that they are completely dependent upon pesticides and herbicides to grow to bear fruit. The symbiotic relationship between biotechnology and agri-chemicals benefits the producers of both substances, however the farmer and consumer suffer because an increase in the cost for the farmer increases the cost for the consumer. Unfortunately for some, this price increase is too much and they can no longer afford to feed themselves. Fortunately for the consumer there is hope. Specifically, in the induced modification method, the seeds created are less dependent upon pesticides and herbicides making the overall cost of production cheaper for farmers. Unfortunately, once the importance of pesticides in farming can be reduced, the chemical producers and suppliers will suffer. Nonetheless, it is apparent that the need to feed the hungry of the world would require a change making better crops more affordable and genetically modified seeds can help. It is important however that the genetically modified seeds used have the ability to reproduce. This is the fear that farmers using the genetically altered seeds, referred to as suicide or terminator seeds, will be completely dependent upon the producers of the altered seeds each
year to grow a new crop because of the seeds’ sterility. This would be a way in which corporations could ensure the continuing dependence farmers have on them. It is important therefore that there is regulation upon these new scientific procedures. These methods should help nations to promote independence and alleviate hunger, not drive them farther into debt and dependence upon corporations for survival.

Linked to the issue of regulation is the importance that politics can have upon the public opinion as well as the policies and economics of a nation regarding the use of genetically altered crops. Throughout the world, some nations have been more accepting of the use of genetically modified foods, while others have banned them completely. Much of the western world has adopted the recent trend of “going organic,” which involves traditional farming methods, using natural forms of pesticides and using seeds that have not been altered using the scientific processes of genetic mutation. These nations have been able to afford this due to their surplus. Many nations around the world, including third world countries, have followed suite. Unfortunately, adopting this method has adversely affected some of the third world nations. With the exclusion of South Africa, all of the African countries have prohibited the use of genetically altered crops and there is no importation of foods that have been genetically engineered. The ban on genetically modified food in both Europe and African has caused the growth in agricultural productivity in both continents to slow down. Before the release of genetically modified seeds into the world market in 1996, European agriculture was
keeping pace with American agriculture; afterwards however, Europe has fallen behind at a steady rate of 1 to 2% per year\textsuperscript{16}. With Europe being one of the main cereal producers in the world, this is a cause for concern\textsuperscript{16}. After Great Britain had begun to decommission their ageing generation of farmers by stopping to provide them with a subsidy, it was clear that Great Britain would not be able to produce enough food to feed their citizens\textsuperscript{17}. Dependence upon imports from other countries has and will continue to increase\textsuperscript{17}. However, Great Britain’s Prime Minister, Tony Blair, had rejected genetically modified crops because they were deemed dangerous\textsuperscript{14}. In the attempt to continue trading unaltered crops with Great Britain and other nations, African countries can no longer feed itself \textsuperscript{14}. Africa’s ban on genetically modified food was in part so their nations could still trade food in the European market but it was also due to the lack of research done on crops that would benefit African nations \textsuperscript{16}. Cassava and yams, two of the main crops in Africa, have had little research done into genetically altering these crops since no significant genetic modification research has been done in Africa \textsuperscript{16}. It is seen here that a vicious cycle has formed and unless something is changed, more and more people will starve.

Unfortunately, nothing can really change unless industrialized nations dispose of the romanticized vision they associate with “going organic.” There is a segment of the population that has a love affair with the idea of peasant agriculture making it a luxury item. One of the major proponents for this is Prince Charles who built a model village in traditional architectural style, creating his own brand of
organic products called Duchy Originals. As author Paul Collier put it, “Peasants, like pandas, are to be preserved. But distressingly, peasants, like pandas, show little inclination to reproduce themselves.” Peasant life is slowly being phased out because of the low income pressuring children to move away and pursue more financially stable futures. However, for those then forced into the peasant lifestyle, these individuals are generally ill equipped to handle the lifestyle of an entrepreneur. The decision to be an entrepreneur is generally a minority decision in an economically stable country; people would rather pursue a wage paying job where there is greater stability and less round the clock work. It is difficult as well for peasant farmers to meet the constantly changing demands and regulations on their small scale farms. It is therefore much easier for commercial agriculture to take on these roles because they are capable of handling the investments, regulations and complicated marketing chains. It can be argued however, that during the European agricultural revolution, peasant agriculture was capable of being incorporated along side commercial agriculture. The peasant farms were able to thrive and therefore a change such as this can also be incorporated into a continent such as Africa. It was much easier to see the innovations produced by local educated peasant farmers being carried over into the methods of larger scale commercial agriculture. This is because innovations are generally specific to the particular area the farming is taking place. In Africa, the soil is complex and high variation is found throughout the continent so such as system as seen in Europe would be difficult, especially with the lack of education, funding, and organization.
African peasant farming has fallen further and further behind the commercial productivity rate of other nations because farmers cannot afford the increasing price of fertilizer. If genetically modified seeds were used, less fertilizer could be used so the cost of production could be decreased. The importation of food into Africa however will continue to increase over subsequent years if there is not a shift to a more commercialized system of farming or incorporation of scientific advances such as genetic alteration. It is therefore important that the focus of industrialized nations should be shifted from the romantic ideal of a peasant farmers working in the hills of his small farm to an integration of technology to help feed the growing population of the world.

Economics and Policies Behind Hunger

As previously mentioned, one of the reasons hunger is still persistent today is due in part to limitations placed upon scientific advancements which is directly linked to poor economic policies. The population of the world is increasing but the production of food is no longer keeping pace. Because of this, the economic growth of nations is creating a supply and demand system that has quickly lost any sense of equilibrium. Although the adoption of the commercialization of agriculture is unromantic, it has been proven in several nations across the globe it is a functional model.

Brazil, India and China are three nations that have moved to commercial agriculture where the incorporation of genetically modified crops has produced
higher profit yields. In both India and China, the crop production per hectare of land has increased seven to ten times that than before the implementation of modern agricultural techniques. In Brazil, agricultural companies have been successful in bringing innovation to small farmers. These companies have adopted policies similar to contract farming, thereby ensuring small farmers have not been completely forced out of the agricultural business. Unfortunately, the Brazilian government has not regulated the growth of these companies, so monopolies have formed reducing competition. The changes these nations have made are isolated to these countries unfortunately and other third world countries are slow to follow suite. This is due in part to the issues of trade dating back to post-World War II.

After the end of WWII, a multilateral form of trade was preferred for trade liberalization. Under this approach, the General Agreement on Tariffs and Trade (GATT) was established allowing member nations to subsidize production or agriculture in addition to exporting and limiting market access to other nations. It was a way for the member nations to limit outsider access while giving each other preferential treatment. This caused commodity food prices to drop and resulted in distortion of global agricultural trade. Outside exporting nations became frustrated because of their non-subsidized agriculture. In order to attempt to bring the market back under control, the World Trade Organization was founded (WTO). The WTO was established to try and help local farmers because when the market was left unregulated, it was working mainly to the benefit of a few wealthier nations.
With the WTO, the market grew more stable and was closer to a state of equality but this was wholly unsatisfying for many nations. Because the WTO is working on a global scale, it must cater to the lowest common denominator to try and deal with the various conflicts and complications between nations and regions of the globe. Working on a global scale will not be completely successful because it is focused too much on ideals and the idea that all nations are completely equal.

Back in 1960, an attempt to bring new technology and equality to developing nations was made by The Rockefeller Foundation. This effort at bringing about change was referred to as the Green Revolution. Unfortunately the Green Revolution did not being about the changes it was aimed to bring about. The Rockefeller Foundation was focused only on increasing the agricultural yield of Asia, specifically that of rice. The revolution then caused a widening gap between the rich and poor in developing Asian nations because only the wealthier farmers could afford the new technologies and fertilizer. Consequently, those with the new technologies cultivated more rice, although this rice was prone to diseases and the rice itself was of poor quality. Asia then began to increase its resources in biodevelopment in the 1980s, and now the idea for a second revolution has become to take hold. This second endeavor is called the Doubly Green Revolution. This time, the goals are focused on not only increasing the yield of crop output but through the incorporation of genetic modification, they plan to do this in a “cleaner and greener” fashion creating healthier and heartier crops.
The importance of this second revolution lies in the fact that the population is steadily increasing and so is the need for food. In Asia alone, 25% of the purchases of agrochemicals come from this part of the world. However, the introduction of genetic modification is not readily accepted by all due to religious conflicts. Strict followers of the Islamic faith are required to eat food free from harmful substances so the inclusion of genes foreign to a plant, especially genes of human origin, could potentially create an “unclean” plant. However even if genetically engineered crops are accepted, the revolution will fail if this doesn’t result in a shift towards a greater balance between supply and demand.

Because of Asia’s population growth, the price of food world wide has increased. As the income of the world increases so does the demand for food; people are able to afford better food in larger quantities. More individuals can now afford to move from a diet of grains and cereals to one that includes more protein. This then drives the price of grain higher so the animals providing the protein can be fed. Unfortunately the price of food increases faster than the income of people world wide, so unless there is an increase in the food supply, the price of food will continue to rise. This will then result in malnourished urban children whose physical and mental growth will be stunted. If the third world countries are to progress into developing nations, the new generations must be fed and this can’t be done without the intervention of modern agriculture. Small, self-sufficient farmers can no longer supply their nations with enough food for the increasing population; reversal of this can only be achieved through significant change.
Conclusion- Reversal of World Hunger

If the advancements seen in India, China, Brazil and even the United States could be carried over into the continent of Africa and Asia, similar results could be seen. However, the incorporation of genetically modified plants cannot reverse the issue of world spread hunger alone. Policies promoting the incorporation of modern farming techniques, coupled with the use of genetically modified crops, could potentially reverse the widening gap between supply and demand.

In order for the developing nations to compete in a global economy, a combination of regional and bilateral fair-trade agreements (FTA) would be established. Under bilateral trade system, countries would give preferential treatment to select countries while continuing normal trade policies with those outside of the FTA. They would be given the option as to what nations they would want to enter into trade agreements with. Regional trade agreements would work in conjunction with the bilateral trade system, operating specifically to aid developing nations. The regional FTA would allow countries to experiment with domestic reforms and testing the waters before entering into full foreign competition. These would help domestic markets cope with the limited foreign completion before entering into the full onslaught as countries would experience under a multilateral trade system. Bans such as those imposed by Africa on genetically modified crops would have to be lifted so that the United Sates along with other nations employing
the use of genetic engineering could export genetically modified crops to help feed the growing populations there.

In conjunction with the bilateral trade system, countries would have to agree to lift subsidies and bans so that there was more of an incentive to export and import goods. The United States currently has a subsidy supporting domestic biofuels. This is because the U.S. is actively searching for a new alternative fuel sources because they want to be rid of their dependence of Arab oil. The U.S. is currently researching the use of ethanol from grain as a viable alternative energy source. It was found however that Brazilian sugar cane is a better source for biofuels, but the U.S. has restricted imports of it to prevent competition with domestic grain suppliers. Because of this, the price of grain used for food has been increased due to some of the grain being diverted to biofuels. If the U.S. agreed to lift this subsidy so long as Europe lifted its ban on genetically modified foods, both nations would profit. Africa may then be enticed to lift its own ban on genetically modified crops. Since Europe would lift this ban, African nations may be spurred on to include the use of genetically modified crops since they could sell their food on the European market.

If more resources were invested into developing nations, such as those in Asia and Africa, this would help increase the development in these areas. African nations have had a fear of larger scale agriculture because if people were forced off their own small farms, they would be forced to move into the cities. The cities currently cannot afford to feed those living there, so an influx of people would cripple these
nations. Riots could occur possibly resulting in violent revolutions. However, if more funding was put towards introducing genetically modified commercial agriculture after Europe lifts its ban on genetically modified foods, nations in both continents could afford to make this switch. Larger commercial agriculture could take hold, even employing local farmers as seen in the Brazilian agricultural model 14. This would provide African governments security knowing that their people were still employed and those in the cities could be fed. Genetically altered crops using the method of mutation induction as discussed earlier could be used since the genome of the plant is not altered by inserting foreign DNA, but only “tweaking” the genes already present in the plant itself. These crops could then be included into the diets of people, such as Muslims in African and Asia who have religious objections to genetic modification.

World hunger is not an easy issue to solve. There is much work that needs to be done, some starting on U.S. soil through policy changes. If the nations of the world came to understand the benefits of adopting a bilateral trade system and making use of regional FTA’s, fair trade between the nations would make it easier to bring about economic change. These economic changes would include lifting bans and getting rid of subsidies on certain crops so there was a greater exchange between nations of food stock. By lifting these bans, scientific advances in genetic modification could be incorporated creating healthier, heartier and more plentiful crops. This would then increase the supply of food world wide, decreasing the price
of food. Nations could then readily afford to feed its people and the third world countries could advance into developing nations.

ENDNOTES


