ON GENETICALLY MODIFIED CROPS IN AGRICULTURE – THE PAST AND THE PRESENT, THE PERIL AND THE POTENTIAL

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Abstract

In recent years, genetic engineering has become one of the most important yet controversial means by which crop plants can be genetically altered. Many GMO cultivars have been released to farmers, and their grains have been incorporated into a variety of food products since 1996. While proponents of GMOs argue that genetic engineering offers unprecedented potential for battling the food shortage worldwide, many Christians and the general public are skeptical about such claims and are reluctant to accept the GMOs. This paper attempts to place the discussions of GMOs in proper context. It first offers perspectives in the context of agricultural history. Considering the long tradition of genetic modification in agriculture, transgenic technology could be regarded as an extension of conventional breeding. The paper then moves on to deal with the potential benefits and risks of GMOs; it addresses unsubstantiated claims in both arguments. It highlights that a more meaningful dialogue has to focus on facts, not speculation. The bulk of the paper is devoted to discussing ethical issues and Christian perspectives related to GMOs. The Christian mandate on truth seeking dictates believers to look at the facts related to GMOs rather than to submit to fear stemming from unfamiliarity or uncertainty with the technology. The stewardship mandate, however, can be interpreted as ground to passionately support or vehemently reject the GMO technology. The scripture clearly does not offer direct guidelines on transgenic technology. Nevertheless, ample examples of cross species gene transfers can be found in scripture, in nature and throughout the agricultural history, without apparent condemnations. If we accept that God is a God of consistency, then GMOs are no exception. A more important role Christians should play is to help better manage the technology to minimize the risks and maximize the benefits. Feeding the hungry is not only in line but called for by the Christian mandate of love and compassion. Transgenic technology could very well be one important tool that can be employed to address the world hunger.

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Introduction

Biotechnology, recombinant DNA and genetic engineering – these "buzz" words are frequently encountered in featured articles of newspapers or popular magazines, heard about on radio or TV. In simple terms, genetic engineering employs a set of techniques to alter the genetic constitution of cells or individuals by the selective removal, insertion, or modification of individual genes or gene sets. It is practiced to achieve one or more of three general goals: to reveal the complex process of how genes are inherited and expressed; to provide better understanding and effective treatment for various diseases, particularly genetic disorders such as cystic fibrosis, Tay Sachs disease, and Huntington's disorder; and to generate novel products, which include improved desirable traits for plants and animals in agriculture and more efficient production of valuable biopharmaceuticals. Organisms derived from genetic engineering are called transgenic or genetically modified organisms (GMOs).

Relative to agriculture, genetic engineering has become one of the most important yet controversial means by which crop plants can be genetically altered. Proponents of GMOs argue that genetic engineering offers unprecedented potential for increasing food production. Crop plants can be modified to produce higher protein content, better resistance to diseases or other environmental stresses, greater tolerance to herbicides, higher efficiency to use fertilizers and ability to self-synthesize fertilizers, etc (Borlaug 2001; Jauhar 2006). These advances would increase the food availability while curtailing agriculture's long standing reliance on synthetic chemicals, fertilizers and higher energy input, thus alleviating the pollution to the environment. Critics, however, are less optimistic about GMOs for several reasons. First, some fear that society does not have sufficient knowledge and wisdom to manage a technology that has direct access to and recombination of genetic material from two different species. Second, some simply argue that the price of employing genetic engineering could be a "cheapening of life" and the loss of what it means to be human (Pence 2002). Third, some contend that GMOs may pose potential threats for agriculture sustainability and bring unforeseen harms to the environment and ecosystems. Fourth, some are concerned with the food safety and public health associated with the release of GMO crops. Fifth, various religious and ethnic groups voice their objections to the use of GMOs based on their core beliefs. Finally, others are concerned with the unintended outcomes and possibility for misuse stemming from human selfishness.

Addressing the GMO controversy requires wisdom, courage, honesty and a desire to seek truth. To that end, it is helpful to review how humans have genetically modified organisms and how agriculture has evolved and become a foundation for civilization during the last 12,000 years. Such review serves to provide an important platform on which modern day GMOs can be discussed in a proper context. Many issues related to GMOs are complex and discussion over them all is undoubtedly beyond the scope of this paper. Instead, this paper will focus on several aspects of GMOs: the current status of GMOs in agriculture, the potential pros and cons of using GMOs, the major points of contention over GMOs, some ethical evaluations and Christian perspectives on GMOs.

Historical Perspectives on Agriculture and Plant Breeding

1. Domestication of plants and origin of agriculture

In a nutshell, crops originated from wild species, which were weeds in ecological terms. No one is certain on when humankind started cultivating plants and tending animals. Two accounts, however, are widely accepted: agriculture began with the domestication of plants and animals; humans have genetically modified and selected plants (animals alike) to suit their needs for thousands of years. The transition from hunter-gatherers to sedentary farmers likely occurred through a series of events. People who gathered wild cereal grains for food around their campsites might have accidentally discovered agriculture through the emergence of the weedy and grassy plants from spilled grains. Subsequently the religious ritual of saving and planting better seeds as an offering to their gods might also played a role in plant domestication. Whatever the initial motives, subsequent observations led to a more deliberate planting, thus creating a more dependable source of food supply, and in turn spawning broader economic and cultural development. In places where wild grains were abundant, humans would have naturally remained for long periods of time, learning how to increase their food supply by saving and planting the best seeds, by protecting grain plants from pests, and by irrigating and fertilizing their crops. (Harlan, 1992)

Selective breeding was the driving force behind ancient agriculture. About 12,000 years ago, humans in the Middle East had already learned to cultivate such crops as barley, lentils, wheat, and peas in the Middle East. In tending these crops, the early farmers identified and selected useful traits (e.g. large spikes, higher yield, non-shattering) against undesirable traits (e.g. weedy, small seeds/pods, lodging). Each time a selection was made, certain traits were favored while others were weeded out. Gradually, mankind altered the characteristics of these plants, making them more nutritious and easier to cultivate and harvest. Better varieties of grains, vegetables and fruits were developed. In turn, these crop plants also became more and more dependent on human's care and less likely to survive in the wild on their own. The selective breeding of traits present in natural population was slow and inefficient. Over the millennia, however, these selections have altered plants' characteristics so much that the traits present in modern crops have very little in common with their ancient progenitors. In fact, most of today's crop plants cannot survive long in the wild without human intervention, a focal point to consider when discussing the assertion of crops becoming 'super weeds'.

Agriculture might have originated independently in other centers as well. Many crops were domesticated in Africa, including yams, okra, coffee, and cotton. In Asia, agriculture was developed based on staples such as rice and soybeans, and many other crops like citrus, mangos, taro and bananas. Agriculture also evolved independently in the New World, beginning as early as 9,000 years ago in Mexico and Peru. For the last five to six centuries, these important crops have been cultivated throughout the world. Wheat, rice, and corn, which provide 60% of the caloric intake of the world today, are cultivated wherever they will grow. (Harlan 1992)

The development of agriculture has had pervasive effects on land. While our hunter-gatherer ancestors lived on once forest land causing limited ecological disturbance, the lifestyle associated with agriculture was not as land-friendly. Deforestation followed by deliberate plantation has altered the landscape significantly: soil fertility has been reduced, soil erosion intensified, and many species (both plant and animals) driven to extinction. Agriculture has been detrimental to the natural environment and ecosystem since its birth, as humans have continued to toil and struggle in converting more forests to farmland. "Cursed is the ground because of you; through painful toil you will eat of it all the days of your life. It will produce thorns and thistles for you, and you will eat the plants of the field. By the sweat of your brow you will eat your food until you return to the ground, since from it you were taken; for dust you are and to dust you will return." (Genesis 3: 17-19).

2. Plant breeding through genetic modification

As one of the most important techniques in agriculture, plant breeding was virtually a hit or miss affair until the late 19th Century. The selective breeding of wild plants by our ancestors was remarkably successful given how little they knew about the inheritance and the dynamics of selection. Horticulturalist Luther Burbank successfully bred many crop species through hybridization, representing the first generation of deliberate cross breeding. During his life time (1849-1926), Burbank was credited for developing over 800 new varieties of fruits, vegetables, trees and flowers. In addition, the re-discovery of Gregor Mendel's basic genetic principles in 1900 triggered a wave of genetic discoveries. The application of these insights, for the first time, made plant breeding more of a science than simply an art.

The transition from selective breeding to cross breeding marked a giant leap forward in the history of agriculture. Plant breeders were able to combine genes from different sources and to create superior genetic combination. They typically began with a set of goals in mind: to enhance resistance to pathogens or insects, to improve nutritional quality by increasing grain protein concentration, to increase yield, etc. They designed crosses between plants of the same species or with a close (sexually compatible) relative. To make a cross, pollen from one plant (male parent) would be transferred to the flower of another (female parent whose pollen had been removed before maturity through emasculation). The resulted seeds would be sowed, the progeny plants screened and examined. Plants that had the most desirable combined characteristics and least undesirable characteristics would be selected to form the base population of a new cultivar, or could be crossed back further to weed out more undesirable traits. Since cross breeding relies upon the sexual reproduction process, it is tedious and time consuming. Every time a cross is made, thousands of genes from male and female parents are mixed. Thus, a large population of offspring needs to be grown in order to recover individual plants having desirable gene combination. This makes the selection of superior plants a process with very low efficiency, as experienced by many plant breeders in conventional breeding programs.

At about the same time as cross breeding matured, innovative approaches were developed to introduce new genes into an existing gene pool. For instance, when genes for particular traits did not exist within a given crop species, either "wide crosses" or induced mutations were employed. The first involves crossing two incompatible species, and later culturing (rescuing) the embryo in a laboratory in order to produce seeds. These seeds would typically produce sterile plants, whose chromosomes are doubled using chemicals to achieve fertility. In essence, the "embryo rescue" has partially overcome the reproductive barrier between sexually incompatible species. When wide crosses are not feasible, a new gene may be created by deliberately mutating plants with physical agents (UV light, x-ray or gamma irradiation) or mutagenic chemicals. The creation of new genes by mutation and their subsequent use in crop improvement is called mutation breeding. Mutation breeding had been widely used since the 1950s. All these techniques, wide crosses, cell/tissue cultures, chromosome doubling, and induction and use of novel mutations, are considered "conventional", despite their reliance upon certain types of genetic meddling by plant breeders. All cultivars or hybrids developed through "conventional breeding" were accepted as normal. No routine analyses of chemical composition of these cultivars were required or practiced.

The "conventional breeding" played an important role in the "Green Revolution" beginning in the early 1970s, which resulted in significant increases in food availability. Maize yield per acre more than quadrupled, from less than 30 bushels in the 1920s to more than 130 bushels in the 1990s. The dramatic yield increases saved many millions of lives in several decades. In one sense, the "Green Revolution" served to meet basic human needs (food & shelter), and thus was fully compatible with the fundamental belief in Christian faith. In another sense, it also mirrored the fallacy of human endeavor in employing technology as the intensive agriculture resulted in pollution to water, environment and ecosystem. While it was often necessary to develop and use new technology to better human lives, we could not escape the reality of the fallen world.

3. Population growth and food supply

The population explosion in recent history has simply outpaced the increase in agriculture productivity. Just 11,000 years ago, there were only roughly 5 million humans who lived on the planet Earth. The initial population growth was slow, due largely to the hunting-gathering lifestyle humans were living. Such a lifestyle limited the family size for practical reasons. A woman on the move simply could not carry too many infants in addition to her household baggage. Women would resort to abortion when unwanted pregnancy occurred or even infanticide when unwanted babies were born. Further, a high mortality among the very young, the old, the ill and the disabled acted as a natural barrier to a rapid population growth. It is without a doubt that neither abortion nor infanticide is compatible with the Christian faith. Yet the more compelling theological issue here is relation between human population size and the nature's capacity to sustain an ever expanding population.

The population explosion became a driving force behind intensive farming, mono-cropping, and the use of chemical fertilizer and pesticides in an attempt to feed the world. Although a century's worth of genetic meddling in plants has made food more abundant and less expensive today than at any other time in history, continuing increases in productivity are necessary to feed the world in the 21st Century if we are to avoid bringing millions of acres of undeveloped land into agricultural use. Food shortage and hunger persist in many regions, even in the midst of a significant increase in agriculture productivity. A conservative estimate states that 774 million people go to bed hungry every day, and about 30,000 people, half of them children, die every day due to hunger and malnutrition (Lacy 2003; Raven 2004). The FAO reports that without an increase in farm productivity, an additional 1.6 billion hectares of arable land will be needed by 2050. Since the human race cannot afford the grave consequences of converting forest to farm land at such a massive scale, we are left with limited options – either increase the agricultural productivity or face a continual food shortage.

The issue at stake here is how to resolve the contention between "being fruitful and multiply" and "work the land." Clearly, the population expansion has outpaced the rising output of the land. The increase in agriculture productivity always seemed to be one step behind. For instance, through technological innovation and aggressive practices, we have achieved a 2.6-fold increase in world grain production since 1950. But this increase in food output is not nearly enough to feed the population. Poverty further aggravates the food shortage (Raven 2004). The World Bank and FAO estimate that one out of every five human beings is living in absolute poverty, unable to obtain food, shelter, or clothing dependably. (Lacy 2003) About one out of every ten receives less than 80% of the daily intake of food calories recommended by the United Nations. There is by far no consensus among theologians on resolving the conflict between the population expansion and stewardship mandate.

Genetically Modified Organisms

1. History in Brief

Soon after the unraveling of the double helical structure of DNA by Crick and Watson in 1953, researchers began to uncover the way by which DNA can be cut and "spliced" back together. The creation of the first engineered DNA molecule through splicing DNA fragments of two unrelated species together was made public in 1972 (Jackson et al., 1972). In such a process, scientists clone a gene of interest from a plant or another organism, attach the gene to a suitable vector (carrier), and transfer the gene into plant cells growing in tissue culture. Once a plant cell has successfully integrated the new gene, a plant will be regenerated, which carries the gene. If the new gene expresses in that plant, it is now called a transgenic plant, or a GMO.

The most notable difference between the development of GMOs and that of conventional crops lies in how genetic manipulation is made. The development of GM crops involves a transfer of one or a few known genes into the host's cell, essentially a surgical alteration of a crop's genetic makeup, whereas the conventional breeding relies upon the mating and subsequent recombination of whole sets of genes from two parents. Because genetic engineering does not involve mixing the entire set of genes from two individuals, this makes the selection of target trait more efficient and precise, a tool regarded highly desirable by almost all plant breeders. Before its insertion into a plant cell, gene of interest is often carefully studied. That knowledge of the function of individual gene(s) and surgical insertion makes it possible to combine traits considered very difficult or impossible to breed via conventional approaches. As will be discussed later, these features – precision, versatility and efficiency, desired by all plant breeders, have also served as a basis for objection to GMOs.

Many GM products have made their way onto our dinner tables since 1996. Given that the first GM plant (tobacco) was developed not long ago (Framond et al., 1983), the advances in transgenic technology were stunning. In 2003, more than 70 GM plant varieties were grown commercially on approximately sixty eight million hectares, in countries such as the United States, Argentina, Australia, Brazil, Canada, Chile, China, Mexico, and South Africa. These

GMOs concentrate heavily on reduced input traits (pest resistance and/or herbicide tolerance) in several major crops including soybean, corn, cotton and canola. (James 2004)

2. Potential Pros and Cons

a. The perceived benefits

Regardless of how genes are transferred, many believe that the benefits of GMOs are evident: alleviating world hunger by increasing crop productivity, reducing environmental degradation from agriculture through lowering the chemical inputs, and generating economic benefits to poor regions by making marginal land more productive. Benefits to consumers are believed to include improved food quality and nutrition, better flavor, more choices and less chemical residues. Some believe that GM crops, in combination with other technologies, might provide solutions to some of the problems already widespread in agriculture. Some Christians find a mandate in Genesis for the use of GMOs in agriculture. In Sam Gregg's words, "Using and altering things of the world for use by human beings, be it food or animals or minerals or whatever, is, in principle, what humans are supposed to be doing. There's an imperative in Christianity in particular, but also in Judaism and Islam, of helping the poor and dealing with questions about poverty and hunger. Hunger is something that afflicts the developing world in particular. Genetically modified food has the potential to radically transform that situation." (Popp 2006).

Several GMOs are often cited as examples that demonstrate the benefits of genetic engineering. The first is the introduction of *Bt* gene from a soil bacterium *Bacillus thuringiensis* to several crops including corn, cotton and soybean. With the *Bt* gene introduced, plants produce a protein toxic to some insects and hence are resistant to these insects. The grains of *Bt* maize were also found to contain low mycotoxin as a result of a lower amount of fungal infestation, and thus showed improved food safety compared to the non-GM corns. Another example is the successful insertion of a gene that provides resistance to the herbicide glyphosate. The herbicide resistance gene allows better weed control through targeted application of herbicide, which reduces competition from weeds, enabling the land to lose less water, and retain more nutrients. In addition, the nutritional quality may be improved through GMO as well. For example, soybean and canola with reduced saturated fats (healthier oil) have been developed. Alterations in the starch content of potatoes and the nutritional quality of protein in maize kernels are being developed. "Golden rice" has been engineered to produce significantly higher vitamin A precursors (β-carotene). This GM rice could play an important role in alleviating the vision loss and/or blindness caused by vitamin A deficiency among those who consume rice as their main staple food.

b. Potential risk with GMOs

There are ample concerns over the use of GMOs. These include: 1) the uncertainties involved in releasing new life forms into the environment and their effects on wild species, weeds, pests and the overall ecological balance; 2) the possible reduction in genetic diversity by relying on a smaller pool of genetically optimized cultivars; 3) the increase in the risk of transferring herbicide resistance from crops to weeds; 4) the creation of more food surpluses in richer countries; 5) the disparity in the distribution of both the benefits and disadvantages of genetic engineering; 6) the discrimination against those who object to GMOs. In addition, some believe that the use of GMO could distract research aiming at more sustainable forms of agriculture which might otherwise effectively reduce some of the damaging effects on soil, water, climate and biodiversity by modern agriculture. Other are concerned with food safety and long-term health effects of GMOs (Pence 2002). The most notable and widely publicized example on negative impacts of GMOs in the ecosystem is concerned with monarch butterflies; it has been claimed that pollen from *Bt*. corn is poisonous to the monarch butterflies. Although the publication was later rejected on poor science and lack of proper control for experiment, the negative sentiment it created toward *Bt*. corn and other GMOs continues to linger to date.

Many Christians who disagree with Sam Gregg on the use of GMOs are concerned with many of the potential risks associated with GMOs. Among them, Calvin DeWitt, a life long conservationist, president of the Au Sable Institute of Environmental Studies, is highly skeptical about Gregg's theology on Genesis. "I think both from an evolutionary biology standpoint and from a standpoint of the Scripture, the belief is that moving genes across taxa--across species, genera, and families--is a kind of abuse of our knowledge of genetics, generally driven not by respect for how creation operates or how biological systems operate, but strictly driven by questions of greed or hubris." (Popp 2006)

It is unethical to emphasize the perceived benefits of GMOs without a proper examination of potential risks and the reality. On the other hand, the concerns and potential risks should not be exaggerated with the intention of impeding permanently the development of GMO technology. Speaking on the prospects for agriculture in the 21st Century, Nobel Prize Laureate and Father of the 'Green Revolution' Dr. Norman Borlaug made this comment: "In crop improvement, we will need to apply both conventional breeding and biotechnology methodologies. The new tools of genetic engineering – if scientists are permitted to use them – can permit accelerated development of food crop varieties with greater tolerance to drought, heat, cold and soil mineral toxicities; greater resistance to menacing insects and diseases; and higher nutritional quality levels...While the affluent nations can certainly afford to adopt ultra low-risk positions, and pay more for food produced by the so-called 'organic' methods, the one billion chronically undernourished people of the low-income, food-deficit nations cannot." (Borlaug 2000)

Ethical issues and Christian perspectives

1. Some fundamental questions

Because food is essential to human life, the genetic modification of foodstuffs matters much more than just the science behind the technology. Any manipulation that can potentially alter the taste, safety, chemical composition and nutritional quality of the foodstuff means a great deal to the public. Thus, the development and use of GMOs have raised more public concerns and interests than any other aspects of genetic engineering. The general public is often interested in broader issues concerning the ethical ground and religious beliefs of using GMOs. For instance, is it right or wrong to genetically engineer plants? Under this umbrella, issues worthy of further examination include the notion of 'playing God', the idea of unnaturalness concerning GMOs, and the appropriateness of introducing GMOs into a complex ecosystem. Other areas of debate center around the Christian mandates on pursuing truth, having compassion with fellow citizens and loving others as thyself.

a. Inherent objection to genetic engineering

The most fundamental question is whether it is right to develop GMOs via genetic engineering in the first place. Opponents often express their negative sentiments towards GMOs as ‘playing God’, unnatural or not the way nature intended (Pence 2002). These represent intrinsic concerns over the genetic modifications of life. The ‘playing God’ notion reflects beliefs on the divinely given goodness and fitness of life ordained by God and God alone; no humans are “qualified” to alter it (Pence 2002). In other words, with finite knowledge and imperfect understanding of the complexity of life itself, humans lack sufficient wisdom to manipulate the genetic basis of life form without bringing unintended consequences. In essence, tampering with the genetic makeup of God’s creation raises questions about the role of man as a steward of God’s creation versus man’s ability to rule over it.

The scripture itself presents two distinct views on man’s role in relation to creation. The first account sets man’s role in stronger terms, “subdue the earth and fill it”, “rule over other creatures.” (Genesis 1) The second account, however, lays out a much softer tone, calling human beings to “work and care for” creation (Genesis 2). Both views, however, depict a special responsibility charged to humans. When considering the origin and evolution of agriculture in the context of “having dominion over every living thing that moves on the earth,” humans have done just that. Through domestications of plants/animals, selective breeding, cross breeding and the use of other technology to advance civilization, we have transformed the natural world to better serve our own needs.

Man’s role as steward of nature effectively reveals the values and principles of ecological holism. The release of GMOs is considered as human intrusion, which causes imbalance to the web of complex inter-relationships among many organisms. ‘Playing God’ in this context is portrayed as inherently negative, implying that we are taking on a role that does not belong to humans but to God alone. “These are matters too high and deep for humanity. It is in God’s wisdom that He created all living things and the complex and interlinked means by which they grow and flourish. Human beings cannot match the divine grace and understanding, and our activities must inevitably spoil what God has made. The story of the tower of Babel in the book of Genesis, portraying a massive but ultimately fruitless building project, epitomizes the folly of human technological action in autonomy from God.” (Bruce & Bruce, 1998) In other words, the act of genetically engineering plants is considered as a process of substituting the created or naturally evolved ‘goodness’ of living organisms with fallible human design.

The objection to GMOs based on the principles of ecological holism is questionable when considered in the context of human history. The fact that agriculture evolution and many technological advances have helped humans build society and civilization, and to better cope with natural forces makes it difficult to adapt an outright rejection of transgenic technology and GMOs. If God is a God of consistency, one can clearly reason that genetic manipulation could well be a tool God has given to humans to cope with nature, thus fulfilling our stewardship role. Otherwise, humans have long been playing a wrong role in created order: they began a long journey of genetic manipulations of plants and animals through selective breeding at the dawn of civilization and continued for thousands of years thereafter. In addition, without the development of agriculture through genetic modification, it is inconceivable that the Earth will be able to sustain the current population, a state that contradicts the command "be fruitful and multiply". Had no genetic modification been made throughout history, humans would still be living a nomadic life as hunters and gatherers. As reviewed earlier, in the most fundamental sense, all plant breeding involves intentional genetic manipulation: selecting useful new genes and weeding out the deleterious ones. If such practices equates 'playing God', then mankind has been 'playing God' since the dawn of civilization.

If an outright rejection of GMOs is not justified by a clear cut theology or supported by the history of agriculture, could one still base his objection on technicality: the stark contrast between conventional breeding and the transgenic technology. In conventional breeding, genes that were incorporated into a crop were limited to those already present in the same or closely related species. Although novel procedures were developed to induce useful mutant genes since the 1940s, the use of mutants was still largely restricted within the conventional breeding paradigm – the transfer of genes within the same or closely related species. The transgenic technology, however, opens the avenue to introducing genes beyond the natural limit of the species boundary. Whether the difference in how genes are specifically manipulated constitutes a ground for support or rejection of GMOs is up to further debate. Nevertheless, the circumstantial evidence in nature and in scripture seem to suggest that mixing genes from two different species is not an issue to God. First, many micro-organisms in nature are free to mix their genomes. Secondly, no condemnation in scripture is voiced against the mule, a product of mixing many genes from two separate species.

b. Christian mandate on seeking the truth

It is vital to note that for Christians, nature is not something just came to existence by accident. Rather, it is creation, the willful product of the wise, loving and omnipotent God. It is given to mankind as a gift, to be treasured with wonder as much as a resource to be used to enhance human living. Gospel John 1:1-3 and Colossians 1:15-17 made it clear that the whole created order is held together and sustained in Jesus Christ, who is the Son of God and the Word that brought into existence all things. Given that God is the owner of everything there is, one may argue that nature, including plants cannot be regarded simply as ours to modify as we please. Each living organism has its unique place in the web of life. Further, we are 'made in the image of God', implying both a unique relationship with God and a special responsibility towards His creation. As stewards, we are to care for creation, which is also given to us for use as food and other purposes. Humans are given the creativity and intelligence to understand nature, to better manage it, to build culture and society as we are charged to "subdue the earth and fill it." Thus, seeking the truth including that of nature and use that knowledge to enhance human life is an integral component of our responsibility.

As recorded in the Old Testament, a variety of technologies were permitted to improve human life: construction, navigation, irrigation, mining for minerals, craftsmanship, and even genetic modification as recorded in Genesis 30: 29-41. The reason behind rapid increases in Jacob's flock can now be explained through a simple genetic phenomenon – there are more heterozygotes (speckled and spotted) than each of the two homozygotes (pure white or pure black). In every breeding cycle, Jacob received 75% of the offspring (25% black, 50% speckled and spotted). The case of Jacob's flock and other examples in the scripture illustrated the biblical mandate on knowledge seeking and scientific innovation. It is a God-given responsibility to build culture and improve society using technology available to us. The truth seeking mandate might serve as a basis for the genetic manipulation of life: in cultivating and reordering the natural world so that it better serves human welfare. In this context, GMOs can be considered as products of reordering the nature. The creativity God has breathed in us to manage the creation can be rightfully regarded as 'playing God' in a positive sense. That is, "human beings act out God's image before the rest of creation, in relationship and obedience to Him."(Bruce & Bruce 1998) In 1 Peter 4: 10-12, we are called to administer God's grace in various forms, "so that in all things God may be praised through Jesus Christ." Since a majority in all religious groups believe that humans should use their knowledge to improve the life of other humans, it would seem strange to exclude GMOs from a long list of technological innovations that can be used to better human living.

On a separate note, truth seeking and knowledge building throughout human civilization has served to preserve human lives and minimize the damage from countless natural threats present to humans. These include diseases, famine, drought, flood, fires, tornados, earthquake, and many more. Genetic modification could be considered as an appropriate use of science and technology for humans to cope with similar threats (chronic hunger and famine). Jesus Himself demonstrates the importance of addressing the fundamental human needs. In John 21:15 and 17, Jesus instructs Peter to "feed my sheep." In all the Gospels, Jesus feeding the 5,000 is recorded. Although we may never understand the science behind the miracle of "five loaves and two fish", it is left with no doubt that feeding people in itself is part of Christ's ministry and therefore should be his followers' as well. If our motivation is to use GMOs for humanitarian endeavors, it is not only compatible with but also called for by the scripture. Attempts made to provide food for those under starvation is an excellent way of showing our compassion towards our fellow citizens, as Jesus himself did repeatedly to the crowd who followed him. The use of technology including GMOs to enhance the life of human beings (feeding the world) seems fully compatible with the Christian mandate on truth seeking.

c. Unnaturalness and safeguard of GMOs

Another line of objection to GMOs contends that they are in some ways unnatural, or not the way nature intended. It is true that we are making possible through genetic engineering what is in many cases impossible in nature – splicing together genes that are not found together in nature. However, as discussed earlier, almost all crops are unnatural, on at least two major accounts. First, they are vastly different from their ancestors or wild relatives. In fact, many agronomists consider most crops as man-made species (Harlan 1992). For instance, some common vegetables, broccoli, cabbage, Brussels sprouts, cauliflowers, kale, are of the same progenitor species. The diversity exhibited among these vegetables is unnatural in appearance, nutrition and many other biological aspects when compared to their original common ancestor. Bread wheat has its humble origin from three different grassy wild species, none of which can produce grains with food values even close to that of *Triticum asetivum*. Second, most crops are now grown in places far from their original site of domestication. Wheat, grown widely in US, most of Asia and throughout Western Europe, was first brought under cultivation in Mesopotamia. The US is the leading producer and exporter of soybeans, which was domesticated in Northeastern China. In fact, most major crops currently grown in North America were originated from somewhere else. In a way, all the major crops in North America are unnatural.

While many have used or heard the term unnatural, it is somewhat difficult to define it. To many, the naturalness may simply mean 'how I remember things were in the past.' For some, 'unnaturalness' may represent uneasiness with the new technology rooted in unfamiliarity and/or lack of understanding. (Bruce & Bruce 1998) On these two accounts, both 'naturalness' and 'unnaturalness' means different things to different people, a relative state difficult to derive an impaired judgment. Still for others 'naturalness' may signify some sort of imagined 'perfect' status quo that once existed but now has disappeared as a result of human intervention. Thus, "the good, old days" seemed always better than the present, and the technological advances (e.g. Industrial Revolution) are to be blamed for all problems we currently have. The dilemma with this line of reasoning is that the 'ideal' state of affair never existed, at least not since the Fall of man. Otherwise, one face immediate challenge explaining the numerous incidences by which the pre-industrial societies had brought wrought to the environment. For instance, the once prosperous cities of Mesopotamia in "Fertile Crescent" became desolate long before industrial revolution had begun, and the productive Indus Valley in Pakistan was destroyed by ancient ancestors' prolonged exploitation of their fragile environment (Hillel 1991).

A seemingly more compelling argument on 'unnaturalness' of GMOs lies in how genetic material is manipulated in the process of development. Because genes determine to a large extent the physical traits that make up an organism, manipulating them directly at the DNA level constitutes making far-reaching and fundamental changes to organisms. Comparative analyses between genetic engineering and the conventional breeding would once again bring the claim of unnaturalness into question. Why is it acceptable to breed selected plants for desired traits through crossing and mutation breeding, but not using more specific, precise technology to accomplish the same goal? How much is the genetic engineering really different from the conventional breeding? No easy or unanimous answer to both questions is available. Many who are familiar with how genetics and breeding work argue that conventional breeding and crop introduction can produce alteration just as dramatic as that of genetic engineering, but with less precision and lower efficiency. Since we have no ethical objections to hybrid corn, and triticale (a man-made species between wheat and rye), there is no solid ground for an outright rejection of GMOs based on how genes are combined.

Others contend that the surgical genetic alteration might have been made before we have had sufficient knowledge or wisdom to do it properly. Calvin DeWitt, for instance, is highly skeptical that humans have the wisdom to play God by shifting around genes in ways that are impossible in nature. (Popp 2006) In conventional breeding, every selection carries with it a complete set of genetic information of both parents. While a target trait is selected, other traits would inevitably be 'carried along', desirable or undesirable. Using transgenic technology, however, gene(s) for specific trait(s) can be worked on, with no other genes or traits being altered. Obviously, the precision and specificity for gene introduction is so profound that it should only be practiced with caution and foresight. This high specificity also translates into more rapid development and release of new cultivars. It usually takes several generations in conventional breeding to reach the homozygote state, the basis for effective selection of target trait. With genetic engineering, alteration and selection could be done in one generation. This stunning pace and high efficiency is disturbing, because it increases the likelihood of serious miscalculation on both positive and negative impacts. The fast pace of transgenic technology may skip over check points for unintended outcomes built into slower steps in conventional breeding.

Realizing the potential problems long before genetic engineering has become a mature technology, a small group of leading researchers published a letter simultaneously in *Science* and *Nature* (Berg et al., 1974) calling for a moratorium to regulate all transgenic research. Soon after, the US and an International Consortium issued guidelines for transgenic research. Specific measures were taken to monitor research and development at all stages. Continuing efforts have been made to update these guidelines. Many areas of research were also prohibited by the guidelines. Although the government regulation and oversight is not bullet proof for potential risks, it does provide a very effective safeguard for transgenic research and use of GMOs. In fact, genetic engineering became the first technology development that provides anticipatory foresight for potential risks and actively imposes self policing in compliance with the government regulation.

d. On eliminating species barrier

Some fear that breeding through genetic engineering effectively knocks down the species barrier, thus disrupting the delicate natural balances existing throughout the ecosystems. It is believed that the practice of transgenic technology serves either to impose our interpretation of what those balances should be or to utterly ignore such balances intended by God (Bruce & Bruce 1998). Therefore, the consequences of genetic engineering might be devastating. Genesis states that God made 'everything according to its kind.' Each kind serves its unique roles in an ecosystem. It is unclear, however, if the 'kind' in Genesis is necessarily the equivalent of the biological unit 'species', which is a human construct that serves to conveniently identify different organisms. Nevertheless, it is widely accepted that the taxonomic unit species does represent at least one aspect of the natural order. Thus to mix different species by genetic engineering would seem to have crossed the natural boundary, thus constitutes the breach of humanity's natural responsibility to other creatures intended by God.

Two related questions worth further examination: the first is whether scripture mandates that barriers between species are not to be crossed; the second is whether genetic engineering sufficiently eliminates the species barrier as critics claimed. The theology on absolute separation of different species is at best questionable. Mules, a hybrid between horses and donkeys, are mentioned in the scripture with no apparent condemnation. As mentioned earlier, many microbes (bacteria and viruses) trade their genes on a regular basis. In fact, humans did not invent the very tools of genetic engineering, we just borrowed them from microbes, including the essential enzymes (restriction endonucleases, ligases, polymerases, etc.) and DNA carriers (vectors). Further, cross-pollination among some plant species also occurs naturally to create gene recombination. It seems inconsistent to suggest that the reproductive barrier among species should never be crossed. Otherwise we would never have had many of the important crops in the first place. These crops, to list a few, including cotton, Irish potato, sugarcane, durum wheat, bread wheat, are all products of cross-species hybridization and subsequent genetic modifications.

It seems also over-stretching to claim that changing one or two genes constitutes a wholesale breach of the species barrier. A transgenic corn with a *Bt* gene is still primarily a corn, which cannot mate with the soil bacteria naturally carrying the *Bt* gene; a soybean with roundup resistance gene is still a soybean; even the 'golden rice', a GMO developed through transferring five genes from a daffodil and two genes from bacteria, remains a rice that can neither interbreed with the bacteria nor cross with the daffodil. Thus, genetic engineering does not remove the species boundary as what is often feared and believed. It is more true to consider genetic engineering as such, one or a few gene(s) is (are) borrowed from another species, which is not equivalent to 'mix' different species since the two species are still incapable of interbreeding. Some even went so far as to suggest that God might intend that at some point when we could undertake genetic engineering, and bring solutions to food shortage, poverty and damage to the environment, even in the midst of human folly and selfishness (Bruce & Bruce 1998).

2. Food safety and mandatory labeling

The cleanness of foodstuff derived from the GMOs is an important issue for many whose religion rejects the consumption of "unclean" food. Once genes are transferred from one organism to another, especially from 'unclean' animals to other animals or plants, are the resulted GMOs "clean" to consume? The Christian theology seems to refute the notion of certain food "unclean" for consumption. Jesus declared all foods clean in Mark 7:19. In Acts 10:13, God declares to Peter in a vision that all animals and birds of all kinds good to eat, even those previously rendered as unclean in Leviticus. Through these examples in the New Testament, the scripture left with little doubt that all foods are clean for consumption.

Some Christians and consumer groups demand zero risk or outright rejection of GMOs. The zero risk philosophy is neither practical nor compatible with the Christian faith. First, no one argues or can guarantee risk-free food produced from conventional breeding. Long before the GMO era, humans have consumed food with known toxins. For instance, chemical analyses found numerous potential carcinogens in coffee. Caffeine, the main stimulant in coffee, is a known mutagen at elevated concentrations. Most would consider it an insanity to stop going to Starbucks based on these facts. Secondly, GMOs have been subjected to much tighter regulations and safety tests, which are not required nor practiced for varieties developed through conventional breeding. Multi-year trials have had to be conducted to gain government approval before the release of GMOs. No health problems have been attributed to GMOs since the beginning of large scale consumption in 1996 (Herring 2007; SOT 2002). On the contrary, research has found that GMOs are actually safer than its non-GMO counterparts because of the strict government regulations over their development and vigorous tests for toxic compounds and allergens. *Bt* corn grains, for example, contain much less mycotoxin due to the decreased infestation by fungi, and much lower chemical residues as a result of substantially reduced application of agri-chemicals (Pryme & Lembcke 2003). Any time a suspect allergen is found and linked to a gene insertion, the development of that GMO is blocked, long before it ever reaches the market place. Most food safety problems stem from post-harvest handling (e.g. microbial contamination), GMO or non-GMO alike.

Even with all the tests and government oversight, zero risk cannot be guaranteed for GMOs, or any non-GMO foodstuffs. As Christians, demanding zero risk and absolute safety is incompatible with our faith. As articulated by the Bioethics Working Groups (2001), "Indeed the heart of the Christian belief involves living daily by the 'risk' of our faith. To reject GM food unless absolute safety can be guaranteed is not compatible with a Christian view of reality, because God did not create our world with such guarantees."

While it is important to respect the right of those who reject GMOs on the basis of food safety, the demand for mandatory labeling represent poor stewardship and questionable theology. The process will require farmers and food processors to separate GM from non-GM grains every step along the way, including a separate storage and handling facility, and tracing when and how much GM ingredients are blended into final food products. The cost involved would drive the food price to a much higher level than most consumers are willing to pay. In the face of lacking any credible evidence showing compromised food safety from GMOs (Herring 2007; Pryme & Lembcke 2003; SOT 2002), mandatory labeling is not a wise use of resource. Realizing the complexity of mandatory labeling, federal agencies have recommended a voluntary labeling system by which the organic and non-GM food products can be labeled for consumers who are willing to pay a premium for these products. The voluntary labeling system serves to respect the right of minority (those who are concerned with GM safety) without having to pass the cost of a mandatory labeling system to the majority. Justice is served for both groups.

3. Ecological impacts of GMOs.

One of the most widely publicized concerns with GMOs centers on their potential effects on environment and ecosystem. Even in the scientific community, a dichotomy in opinions on their ecological impacts persists. While laboratory scientists tend to assert the potential positive impacts, most ecologists are less willing to praise GMOs. There are good reasons for optimism by laboratory scientists. Special cares and foresight had been practiced since the onset of genetic engineering research in early 1970s. A system was set up and continues to evolve in attempts to avoid and minimize potential risks, predicted in advance on the basis of science. As a standard practice, GM crops are developed following government agency's strict regulations. Once a new gene is introduced, a GM crop is planted for field trials and monitored over a period of time against a range of risks. The performance of the desired trait (s), and the interactions of GM plants with other species and the wider environment are carefully evaluated. There have been very few incidences where a GMO has shown unintended, damaging effects on the environment or has gone out of control.

Ecologists have good reasons to express a more conservative view on GMOs. They are concerned with their long term impacts in ecosystem and possible gene flow into the wild relatives or weedy species. Given the complexity of ecosystem and our finite understanding of nature, our hindsight, self-interest or prejudice, it is inherently difficult to predict with certainty and objectivity the long-term effects of GMOs. Either our predictions could be wrong, or we can fail to see outcomes that are blatantly obvious, both of which may have dire consequences. In general, gene flow to the wild could occur in several ways: volunteer crops, wide crosses between GM crops and their wild relatives, and pollen transfer from GM crops to weeds. History has shown that environmental impacts by newer technology were not felt until after relatively long periods. Given that genetic engineering is a relatively young technology, and many fundamental questions still remain to be answered, it would seem wise to take a precautionary approach.

There is no better place to demonstrate our God-given stewardship role than to manage the GMO technology. Since conventional breeding cannot keep up with the population explosion, GMO may be one of the better tools we can use to produce a greater diversity and high quality of safer food on less land, while conserving soil, water and genetic diversity. As Christians, we are called to search for truth and seek understanding. GMOs hold potentials both ways, and the stewardship mandate calls for a wise use of knowledge and technology to maximize the benefits and minimize the potential risks. It is our responsibility to promote the safe use of GM crops; and to bridge the open and honest dialogues among general public regarding GMOs. Failure to shaping the wise use of GMOs represents failure as God's steward, which may have dire consequences.

Some assert that the release of GMOs would disturb the delicate interactions and balances of natural systems. (Nottingham 2002) This line of argument was first formulated against mono-cropping in modern agriculture, long before the GMO era. More specific issues at stake include the notion of crop becoming 'super weed', gene escape from crop to wild species, and long term disruption of ecosystem. It is without much difficulty to dismiss the notion of crop becoming super weed. Since crops are products of genetic modifications during a span of thousands of years, the chance of crop's survival in the wild without cultivation is minimal. (Harlan, 1992) As mentioned earlier, except the target trait, the overall genetic background of a GMO is still the same as its non-GMO counterpart, which cannot survive the wild long without our care. In fact if crops can thrive in the wild by themselves, no agricultural practices shall be necessary. Any farmer or gardener can attest that only weeds can thrive on their own.

The concern over gene escape from GMOs to their wild relatives is genuine and worth careful and continual evaluation. (Nottingham 2002) The prospect of such gene escape, nevertheless, applies to non-GM crops as well. My personal involvement in a research aimed at developing "Clearfield" wheat may best illustrate this point. The herbicide resistance of "Clearfield" wheat was derived from a single mutation induced by treating seeds with a mutagenic chemical. A single resistant plant was identified among thousands of seedlings emerged from treated seeds. Because no transgenic technology is used, "Clearfield" wheat is considered as a non-GMO. These "Clearfield" cultivars, already gained approval and released to farmers, will have the same potential as their GMO counterparts regarding the escape of herbicide resistance gene to their wild relatives. The equal probability in gene escape, however, does not in any way negate the potential risk with GMOs. It does put the ecological concerns over GMOs in proper context. In addition, it encourages the practice for special cares and foresight in using any technology in order to minimize the harmful and unintended consequences.

Fortunately, continual monitoring over 10 years found no substantive evidence of gene transfer to wild species (Herring 2007). The risk of gene escape can be further minimized through crop rotation and better land management. Since ecological impacts often cannot be properly assessed within a short period, continual and long term observations will be necessary. On the other hand, it is unethical to block a technology with potential to save millions of lives simply based on imagined ecological consequences. Speaking at the Vatican conference concerning genetically modified organisms, Peter H. Raven, a Pontifical Academician and Director of Missouri Botanical Garden, made these comment: "There is no ecological theory that supports the idea of wild plants acquiring a transgene and then wrecking havoc in a natural community, but plenty of examples of introduced, invasive plants that have not been genetically modified playing such a role. While common sense must be a guiding principle, it is not logical to imagine consequences that have never been observed at the cost of denying people access to food or adequate economic return for their efforts. Simply to repeat the claim that widespread problems are likely to occur, or that the operation of nature is so mysterious that we can never know what will happen denies logic and flies in the face of the available facts at the cost of hungry people who deserve better treatment from those of us who are so much more fortunate than them." (Raven 2004)

Summary and concluding remarks

There appears to be no solid theological ground or sufficient evidence to suggest a ban on the development and use of GMOs. Plant domestication, selective breeding and cross breeding have been practiced for millennia to alter the genetic composition of crops in order to better suit human needs. GMOs could be considered as an extension to the conventional breeding. There is of little doubt about the potential of GMOs. The Christian mandate on truth seeking dictates an objective and factual review of GMO technology, not an emotional reaction to it. The stewardship mandate, on the other hand, requires an active role by Christians in shaping the wise use of GMOs for humanity, especially for those in need of basic nourishment.

If the claim to feed the world using GMOs is to have any real meaning, however, serious effort and specific steps need to be taken to address the nutritional needs of the poor. The majority of GMOs have been developed and released in the US and Western Europe, where there is no food shortage. Some GMOs with engineered traits like better taste, coloration or freshness, and longer shelf-life are clearly directed at consumers in rich nations, rather than alleviating world hunger. On a utilitarian basis, one could always argue that GMO technology is capital intensive, requiring significant up-front investment. Only these traits developed to the consumer markets of richer nations are likely to generate significant paybacks. Given this argument, more capital investment has to be made to the less profitable projects designed to feed the poor. Otherwise the 'feeding the world' claim becomes a sugar-coating for hidden motives of generating more profits, and it becomes difficult for the general public and Christians to support GMO development. "In general, the more the primary benefit is economic profit for a few, or a relatively trivial consumer choice for those who can afford it, the less Christian ethics would justify the risk." (Bruce & Bruce, 1998)

With potential to make a significant impact in human lives, GMOs are here to stay. The debate over their use will continue for years to come. Ongoing dialogue will help formulate a better strategy to guide the use of GMOs. A vital role Christians must play is to help direct the use of transgenic technology to providing more food for those who live under malnutrition. There is little doubt that feeding people in itself is a ministry clearly modeled by Jesus. GMOs can make that difference in feeding the hungry world. As former US President Jimmy Carter states, "Genetic engineering is not our enemy, but the world hunger is." When asked about what the Christian response to genetic revolution should be, Dr. Francis Collins, the Director of the Human Genome Project, had this to say: "There is no point in throwing our hands up and saying, 'This stuff is dangerous and we don't want anything to do with it.' That would be the worse response the Christian community could have. Rather, it would be best to learn the facts and then begin to participate in a meaningful way in the many coming debates about the uses and misuses."(Demy & Steward, 1999) Participation in debates "in a meaningful way" can help us make an informed, educated stand on GMOs. As philosopher Joseph Joubert states "it is better to debate a question without settling it than to settle a question without debating it."

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