Advances in Science:

Uses of Genetically Modified Foods

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Then God said: "Let us make man in our image, after our likeness. Let them have dominion over the fish of the sea, the birds of the air, and the cattle, and over all the wild animals and all the creatures that crawl on the ground." God created man in his image; in the divine image he created him; male and female he created them. God blessed them, saying: "Be fertile and multiply; fill the earth and subdue it. Have dominion over the fish of the sea, the birds of the air, and all the living things that move on the earth." God also said: "See, I give you every seed-bearing plant all over the earth and every tree that has seed-bearing fruit on it to be your food; and to all the animals of the land, all the birds of the air, and all the living creatures that crawl on the ground, I give all the green plants for food."And so it happened. God looked at everything he had made, and he found it very good. Evening came, and morning followed–the sixth day.[1]

Plant Biotechnology

With the advent of molecular biological tools, modern biotechnology is generating revolutionary advances in genetic knowledge and the capacity to change the genetic makeup of crops. The rapidly expanding field of genomics is providing new molecular tools to greatly accelerate and more precisely target conventional plant breeding. This same knowledge is being applied to transfer genes both across and within species to create transgenic varieties, popularly known as genetically modified organisms.

More specifically, the process of plant transformation has become routine and widespread as evidenced by the many examples of the transformed crop species that abound in the literature. Manipulation of the genetic information of the plant genome

[1]Genesis 1:26–31 NAB.

represents a continuation of a long tradition of mankind's involvement with various plants species that have furnished man with food throughout the centuries. Since the dawn of history, the fates of countless human civilizations have been intertwined with the abundance or scarcity of food. Consequently, manipulation of the food supply or changes in production have, throughout history, raised concerns and have gained acceptance slowly. Thus, the technological advancements currently available, as well as those possible with direct genetic engineering, are not without controversy.

Today this debate is exacerbated by unrelated concerns of globalization, fear of large multinational corporations, market protection, and others. But it is within the context of agricultural history and evolution that these new techniques are most clearly viewed. The object of this essay is to present a brief technological overview of genetically modified foods, and examine this technology in light of both the agricultural evolution and Church teachings.

Genetic Transformation of Plants

All prokaryotic and eukaryotic[2] organisms share the same system of coding for protein expression products and, with some variations, the same apparatus for translating genetic information into proteins. Thus coding sequences from different organisms can be placed into plants with the appropriate plant regulatory sequences.

From a biotechnological view, one of the advantages of working with plants as opposed to other organisms is the totipotency[3] of plant cells. Practically, this means that functional whole plants can be regenerated in vitro from a variety of sources, not only from egg cells and embryos. Systems to regenerate and maintain plants in cell culture lines have become routine and widely adopted. There are basically two techniques used to transform a plant cell via the stable insertion of a foreign gene into the plant's genome in order to regenerate a new plant.

One technique, popularly known as biolistics,[4] relies upon the physical insertion of the new genetic material into plant cells. In this technique, the genetic material to be introduced into a plant genome is coated onto some type of particle, usually gold, and physically propelled into a plant cell by a force that originates most commonly from a blast of helium gas. A small proportion of the DNA-coated particles penetrates the cell membranes as well as the nuclear envelope. By a poorly understood mechanism, the DNA from an even smaller proportion of the coated particles

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[2]Prokaryotic cells do not contain a distinct nucleus, and are charactreistic of such organisms as bacteria. Eukaryotic cells do contain a nucleus, the location for hereditary DNA in multicellular organisms. Some useful definitions are available at: http://www.epicyte.com/glossary.html.

[3]Totipotent: having unlimited capability. Totipotent cells have the capacity to specialize into extra-embryonic membranes and tissues, the embryo, and all postembryonic tissues and organs. See: http://www.nih.gov/news/stemcell/primer.htm.

[4]Biolistics is a term coined by the inventors of transformation technology (biological ballistics). The original apparatus utilized twenty-two-caliber blank shells. J.C. Sanford, T.M. Klein, E.D. Wolf, N. Allen, "Delivery of substances into cells and tissues using particle bombardment process," *J. Particle Sci. Tech.* 5 (1987): 27–37.

uncoats from the particles and becomes stably integrated[5] into the genomic DNA of the plant cell. Concomitant with the gene of interest, a second gene (the selectable marker) coding for some type of resistance, e.g. a herbicide resistance, is also inserted into the genomic DNA. Only those cells that have successfully integrated the gene of interest and the selectable marker will survive the subsequent cell culturing, which selects only transgenic plant cells. These cells can then regenerate into whole plants.

Alternatively, the ubiquitous soil bacterium *Agrobacterium tumefaciens* provides a mechanism to insert a gene of interest and selectable marker into plant cells to bring about the genetic transformation of plants. In nature, *Agrobacterium tumefaciens* exists as a plant pathogen that is responsible for crown gall disease in plants. Infection of the plant by *Agrobacterium* results in the generation of a large mass or gall of undifferentiated tissue on the infected plant. Research into the pathogenesis of this organism reveals that the generation of the gall is induced by the insertion of specific bacterial genes into the genomic DNA of the infected plant cells. Once researchers successfully characterized the genes involved in the transfer of the bacterial DNA and understood, at least partially, the mechanism of this transfer, it became possible for researchers to genetically manipulate *Agrobacterium*, and to induce the bacteria to insert specifically engineered xenogenic genes[6] to genetically alter plants. Transgenic plants are plants in which genes from another organism have been inserted. into the plant genomic DNA.

Regardless of the method used to introduce new genes into the genome of a plant cell, transformed plant cells that have been selected by various selective pressure techniques to carry a gene of interest are manipulated in tissue cultures and induced to differentiate into whole plants. These plants are grown, permitted to go to seed, and then maintained by conventional breeding to perpetuate the plant line indefinitely. The resulting transgenic plants are virtually indistinguishable from their nontransgenic parents, except for the expression of two or three newly introduced genes amidst a backdrop of some 50,000 genes already expressed in the plant.

Transgenic Traits

Genetic manipulation of food crops falls into three categories, namely the introduction of specific traits which lead to changes in the agronomic practices (input traits), the use of the crop species as a production tool to produce large amounts of recombinant proteins such as pharmaceuticals or industrial enzymes (output traits), and specific changes in the nutritional qualities of food.

The initial introduction of genetically modified crops came about with the introduction of crops that had specific, engineered input traits that included insect, dis-

[5]The opposite of this would be the transient expression of a gene inserted into a plant cell. The stable integration of a gene into a plant cell means that subsequent generations of the plant will inherit the gene in Mendelian fashion.

[6]*Xenogenic cells*: cells taken from another species, then transplanted into the recipient. More recently, this term has also come to refer to the expression of genes taken from one species and then transformed into a recipient species.

ease, and herbicide resistance. Table 1 lists some of the product traits that have introduced into food crops.

Table 1

Input Trait	**Crops**
Insect Resistance (e.g. Bt protein)	Corn, Cotton, Canola, Potato, Tomato, Wheat, Soybean, Sunflower
Herbicide Tolerance (e.g. Glyphosate)	Corn, Cotton, Canola, Rice, Soybean, Sugar Beet
Viral Resistant Plants	Sweet Potato, Cassava, Corn, Rice, Squash, Papaya, Tomato, Banana

An attractive early application of input trait technology was the introduction of insect-resistance genes into crops. With this technology, plants could be specifically engineered to express insecticidal proteins that protected them from insect damage. For example, a gene encoding an insecticidal protein (the Bt protein) specific for Lepidopteran larvae was taken from the bacteria *Bacillus thuringiensis* and specifically engineered into corn to express in the green tissue of the plant. Thus, when European corn borer larvae (*Ostrinia nubilalis)* feed on this tissue, the Bt protein in the ingested tissue rapidly degrades the gut of the larvae, resulting in death in the same manner as when the Bt protein is used as a foliar spray. In this way, the use of these transgenic plants alleviates or even eliminates the need to spray corn fields with pesticides when high populations of European corn borer larvae are present. Other production problems, such as those caused by weed manifestations, have also been reduced by the same type of engineering. Farmers in the U.S. have rapidly adopted this type of technology because it protects yields and simultaneously reduces the need for chemicals. Approximately 40% of the U.S. corn crop is now grown using transgenic plants. This figure would doubtless be greater without concerns about the export marketing of these crops.

Following upon input trait agricultural engineering, advances were made in the development of output traits that capitalized on the tremendous production capacity of various crops to produce products that directly benefit society, such as pharmaceuticals and industrial enzymes. Included among these products are pharmaceutical proteins that, prior to this technology, could not be produced in large quantities due to limitations in fermentation or production capacity. With the use of output trait technology, enzymes for commercial use can be produced cheaply and in very large quantities by growing large acreages of plants containing the industrial enzyme. In many cases, the grain containing the enzyme can be used directly in the industrial application.

Another promising line of research is the development of so-called edible vaccines. In order to produce such vaccines, the antigen of a virus is introduced into edible portions of transgenic plants.

Testing of such vaccines in both animals and humans has yielded positive results. In the initial phases of experimentation, when edible portions (e.g. grain) of plants containing an antigen were fed to animals in specific doses, animals were protected from the subsequent challenge of illness due to the specific virus. To date, in clinical trials, experimental testing of edible vaccines in humans has also been successful: the human immune system recognizes the antigen and reacts in an appropriate manner.[7]

The experimental success of edible vaccines to date is a source of great hope for many who believe this technology could be an important tool in fighting major infectious diseases, such as AIDS and malaria. Such grain-based products could be delivered to distant populations, simplifying distribution and administration, as well as lessening dependence upon cold chains. Table 2 lists some of the current output traits currently under development or nearing the market.

Table 2

Output Traits	Examples	Crops
Monoclonal Antibodies	*Herpes Simplex* Virus	Rice Corn Alfalfa
Therapeutic Proteins	Blood Serum Proteins Blood Clotting Agents	Corn Tobacco
Edible Vaccines	Transmissible Gastroenteritis Virus (TGEV-swine) Immunodeficiency Virus (Human and Simian) Hepatitis Rabies	Corn Tobacco
Industrial Enzymes	Trypsin Enzymes (Paper and Pulp Bleaching) Bleaching Enzymes (for manufactured forest products)	Corn Rice

[7]T.G. Lauterslager, D.E. Florack, T.J. van der Wal, J.W. Molthoff, J.P. Langeveld, D. Bosch, W.J. Boersma, L.A. Hilgers, "Oral immunisation of naive and primed animals with transgenic potato tubers expressing LT-B," *Vaccine* 19 (2001):2749–2755.

Concurrent with the advent of these products is the rapid of advancement of crops that carry specific food-enhancing genes. Food enhancing genes are used to reduce the levels of naturally occurring toxins and to add nutrients and beneficial compounds in certain products. Trace levels of naturally occurring toxins and carcinogens are present in all foods, since food products derive from living systems that have evolved to produce chemicals that serve as protective mechanisms from damage caused by insects, fungi, or herbivores. Thus, most individuals consume trace levels of 5,000 to 10,000 toxins daily.[8] For some (including this author), drinking decaffeinated coffee from a plant genetically engineered to silence the caffeine pathway holds far greater appeal than consuming normal coffee containing trace amounts of methylene chloride or ethyl acetate. Below is a sample listing of products approaching the marketplace.

Table 3

Trait	Crops
Increased Levels of Lycopene (an antioxidant)	Tomato
Soybean Oil (80% monounsaturated fat;33% less saturated fat than olive oil)	Soybean Canola
Removal of Allergenic Proteins	Peanuts
Decaffeinated Coffee & Tea	Coffee, Tea

Crop Genetic Engineering and Agricultural Evolution

What has been, that will be; what has been done, that will be done. Nothing is new under the sun. (Ecclesiastes 1:9 NAB)

According to legend, on a hot day in July, 1820, Col. Robert Gibbon Johnson stood on the courthouse steps before a group of his fellow citizens with the avowed intent of demonstrating that tomatoes were not poisonous. Selecting a tomato from the tray before him, he promptly consumed the “venomous” fruit. Nothing happened, and so he consumed another and yet another. He survived the episode, thus dispelling the popular belief that tomatoes, now a mainstay of culinary arts, were poisonous.

In the context of agricultural history, the legend illustrates an important truth. Throughout history and especially in the last millennium, domesticated hybrid crop varieties result from the cross-breeding of crops, through both direct human intervention and spontaneously in the wild. Cross-breeding of plant species is a form of genetic modification that occurs both naturally and “nonnaturally” when people in-

[8]B.N. Ames, L.S. Gold, “Chemical carcinogens: too many rodent carcinogens. *Proc. Natl. Acad. Sci* 87 (1990): 7772–7776.

tervene. For instance, modern wheat varieties came about through the domestication of wild grasses over 10,000 years ago when our ancient forebears "tested" (doubtless taking some risks) thousands of wild plants in what is now modern day Iraq. Eventually, a relatively narrow set of plants came to serve as the human food supply.

Throughout the subsequent millennia human intervention has rapidly and radically changed these initially wild plants. Genetic engineering experiments eliminated weedy traits, reduced grain shattering, and increased yields. Modern bread wheat arose a relatively short time ago, about 4000 years ago when agricultural engineers crossed tetraploid wheat (pasta or durum) with inedible goat grass. Similarly, the ubiquitous modern strawberry arose just recently in the mid-eighteenth century in France as a result of an accidental crossing of two wild species of strawberry, one from the state of Virginia, and the other from Chile. In short, modern food crops are only distantly related to their wild ancestors, and exist because of man's direct genetic intervention and continued maintenance of desirable crops.

Viewed in the light of agricultural history, concerns about risks or ethics of genetically altering plants that comprise the human food supply do not hinge on human intervention, since our participation in producing new crop varieties has always been a part of agricultural history. Thus, as with all new technologies, we must evaluate the ethics of genetic agronomic engineering on its merits, considering its potential to contribute to the health and well-being of humankind, as well the tools used to achieve this end.

Because of urbanization, few people have any direct connection or knowledge of agronomic history and modern day mass food production, and even fewer have any direct knowledge of contemporary tools and techniques used to modify or transform crops, despite the fact that contemporary genetic intervention has been practiced for many years in the continuing evolution of man's food supply. Concerns about genetic engineering often stem from this lack of knowledge and experience.

Some commonly expressed concerns include:

- Production of allergenic/toxic proteins that are not native to particular crops.
- Adverse effects on non-target organisms, especially pollinators (e.g. bees) and biological control organisms.
- Loss of biodiversity.
- Genetic pollution (i.e. unwanted transfer of genes to other species).
- Development of pest resistance.
- Global concentration of economic power and food production.
- Lack of "right-to-know" (i.e., a desire for labeling of transgenic foods).

While it is not within the scope of this paper to address these concerns individually, several more general points can be elaborated.[9] As a whole, society is comfortable with the crossbreeding of domesticated plants with wild species to arrive at new

[9]For a clear explanation of many of these concerns, I refer the reader to an article by Professor Channapatna S. Prakash, "The genetically modified crop debate in the context of agricultural evolution. *Plant Physiology* 126 (May, 2001): 8–15.

varieties. Yet, this conventional process, whereby new chromosomal fragments and hundreds of new genes (some of which potentially encode for toxins or allergens) are introduced into a plant concomitantly, is not routinely tested for food safety or environmental risk factors. Such conventional crossbreeding is also not subject to regulatory oversight, since long-term health aspects of this process are not a cause of concern.

Product labeling of foods that are genetically modified is virtually impossible, since all crops in the human experience of food are genetically engineered to some extent. As agronomic processes have progressed with technological advances, consumer concerns have shifted from the contents of food products to the processes by which such foods have come about. Thus, a breakfast cereal containing wheat might be either wet milled or dry milled, but such differences in processing have not piqued the interest of most consumers until recent years.

Plant Genetic Engineering in the Light of Church Teaching

The Church has not explicitly pronounced itself on limits and use of plant biotechnology. As a rule, the Church advocates prudence and regulation. In considering the ethical application of recent agronomic advances, Church teaching on the unique position of man in relation to nature is fundamental. In understanding this foundational relationship, the Church has often returned to the book of Genesis to understand both the homocentric position of humankind among the natural created world, and the gift of creation itself. This understanding is elaborated in the following passage:

> Man is the image of God partly through the mandate received from his Creator to subdue, to dominate, the earth. In carrying out this mandate, man, every human being, reflects the very action of the Creator of the universe . . .. (I)t can be understood as the whole of the visible world insofar as it comes within the range of man's influence and of his striving to satisfy his needs. The expression "subdue the earth" has an immense range. It means all the resources that the earth (and indirectly the visible world) contains and which, through the conscious activity of man, can be discovered and used for his ends. And so these words, placed at the beginning of the Bible, *never cease to be relevant.* They embrace equally the past ages of civilization and economy, as also the whole of modern reality and future phases of development, which are perhaps already to some extent beginning to take shape, though for the most part they are still almost unknown to man and hidden from him.[10]

Thus, man's dominion over nature is not unregulated power, but stewardship. Stewardship is understood as a cooperation with the Creator. Pope John Paul II has also elaborated this proper position and attitude of man in relation to creation. The duty of man as "the Creator's 'co-worker' is ... one marked by precise boundaries that can never be transgressed with impunity."[11]

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[10] *Laborem exercens* no. 4.

[11] John Paul II. Address on the Jubilee of the Agricultural World, November 11, 2000.

Similarly, in another document, we read:

> In the very first pages of Scripture we read these words: "Fill the earth and subdue it." This teaches us that the whole of creation is for man, that he has been charged to give it meaning by his intelligent activity, to complete and perfect it by his own efforts and to his own advantage. Now if the earth truly was created to provide man with the necessities of life and the tools for his own progress, it follows that every man has the right to glean what he needs from the earth. The recent Council reiterated this truth: "God intended the earth and everything in it for the use of all human beings and peoples. Thus, under the leadership of justice and in the company of charity, created goods should flow fairly to all."[12]

Thus, it is in the context of this understanding that we must evaluate the application of genetic tools to plants, not the tools themselves. It is also important to emphasize that we are dealing only with the application of these tools to plants; the application of genetic engineering to animals and man himself has moral and ethical concerns far beyond the scope of this essay. However, the acceptance and use of agronomic genetic technology, although fundamentally new, has tremendous potential "to foster the development of each man and of the whole man."[13]

Research that proceeds with respect for the human person and the proper role of man in the order of nature, and that is directed toward the flourishing of human potential is encouraged. Stewardship includes not only care for the gift of creation, but the proper exercise of human gifts of intelligence:

> By dint of intelligent thought and hard work, man gradually uncovers the hidden laws of nature and learns to make better use of natural resources. As he takes control over his way of life, he is stimulated to undertake new investigations and fresh discoveries, to take prudent risks and launch new ventures, to act responsibly and give of himself unselfishly.[14]

Thus the application of this technology must occur in the importance of establishing the rights of man and his responsibilities towards all of creation,"to act responsibly and give of himself unselfishly."

In his encyclical *Laborem exercens,* Pope John Paul II writes:

> The very process of "subduing the earth," that is to say work, is marked in the course of history, and especially in recent centuries, by an immense development of technological means. This is an advantageous and positive phenomenon, on condition that the objective dimension of work does not gain the upper hand over the subjective dimension, depriving man of his dignity and inalienable rights or reducing them.[15]

And again, in the same document, he urges prudence and the necessity of right morals:

> On the contrary, the experience of recent years shows that unless all the considerable body of resources and potential at man's disposal is guided by a

[12]*Populorum progressio* no. 22.

[13]Ibid, no. 14.

[14]Ibid., no. 25.

[15]*Laborem exercens,* no. 10.

> moral understanding and by an orientation towards the true good of the human race, it easily turns against man to oppress him.[16]

New technologies which hold vast potential for the good of all humankind must be undertaken with an awareness of the dignity of every person, with the primary goal of allowing all people to reach their potential, and have life abundantly. Research, then, must be

> ... in keeping with the specific needs of the human being-man or woman, child, adult or old person-implies, especially for those who actively share in this process and are responsible for it, a lively awareness of the value of the rights of all and of each person. It likewise implies a lively awareness of the need to respect the right of every individual to the full use of the benefits offered by science and technology.[17]

In addition, Church teaching on the conditions for research, as well as the development and use of new technologies are stated clearly in the Catechism of the Catholic Church:

> Science and technology, by their very nature require unconditional respect for fundamental moral criteria. They must be at the service of the human person, of his inalienable rights, of his true and integral good, in conformity with the plan and the will of God.[18]

In his address to agricultural workers on November 11, 2000 on the Jubilee of the Agricultural World, Pope John Paul II again echoed this responsibility:

> This is a principle to be remembered in agricultural production itself, whenever there is a question of its advance through application of biotechnologies, which cannot be evaluated solely on the basis of immediate economic interests. They must be submitted beforehand to rigorous scientific and ethical examination, to prevent them from becoming disastrous for human health and the future of the earth.[19]

It is clear, then, that plant biotechnology must be carefully examined in relationship to man. Bishop Elio Segreccia, Vice President of The Pontifical Academy for Life, summed it up in this manner: "The biotechnological products must contribute to man's well being, giving guarantees in face of possible risks. Therefore, what is needed is honesty."[20]

Gifts of Creation

In summary, the development and use of modern genetic engineering to food crops and plants in general, must be understood in the context of man's continuing

[16]*Sollicitudo rei socialis,* no.28.

[17]Ibid., no. 23.

[18]Catechism of the Catholic Church, no. 2294.

[19]John Paul II. Address on the Jubilee of the Agricultural World, November 11, 2000.

[20]ZENIT Jan. 27, 2001. Available at: http://www.Zenit.org. See also a recently published document by The Pontifical Academy for Life: "Biotecnologie animalie vegetali: nuove frontiere e nuove responsabilità," G. Ancora, et al. Libreria Editrice Vaticana 1999. ISBN 8820927144

intervention in the improvement of the plants that constitutes his food supply. Many contemporary concerns about the application of these techniques have their counterparts in history, thus reflecting humanity's deep intimacy with food. Debates and discussion about the concerns of this technology must occur in an open and honest intellectual forum, and as previously mentioned, "the risks should be carefully followed through with openness, analysis, and controls, but without a sense of alarm."[21]

Finally, the promise of new technologies might best be viewed as another tool for the benefit of all in humankind's continual utilization and discovery of the gifts of creation, as long as the use of these tools are "guided by a moral understanding and by an orientation towards the true good of the human race."[22]

> When we have spread on earth the fruits of our nature and our enterprise—human dignity, fraternal communion, and freedom—according to the command of the Lord and in his Spirit, we will find them once again, cleansed from the stain of sin, illumined and transfigured, when Christ presents to his Father an eternal and universal kingdom ... here on earth that kingdom is already present in mystery.[23]

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[21]Bishop Elio Segreccia, Vice President, Pontifical Academy for Life (quoted in *Observer*, London, November 28, 1999).

[22]*Sollicitudo rei socialis*, no. 28.

[23]*Gaudium et spes*, no. 39.