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GENETIC ENGINEERING AND THE FOOD SUPPLY

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GENETIC ENGINEERING AND THE FOOD SUPPLY

A PROBLEM IN LIEU OF THESIS

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As food sources high in the trees became inadequate, our predecessors climbed to the ground and through centuries of adaptation learned to stand upright and cultivate plants. Plant cultivation has been practiced for more than ten thousand years with continuous improvements made to crop plants to meet the growing food needs of human and domesticated animal populations.

Biotechnology is the manipulation of living organisms to alter specific organism characteristics. Biotechnology has been practiced for thousands of years with fermentation of fruits and grains to make wine and beer and the use of yeast in baking. More recently, advances in molecular biology allow the analysis and manipulation of genetic material to achieve desired changes in the organism. Transgenics or genetic engineering is the process of identifying specific genetic defects or desirable traits and altering an organism's DNA by addition or deletion of specific DNA sequences.

Nearly 100 million acres (40 million hectares) were planted in transgenic crops in 1999. The largest acreages of the more than 40 different transgenic crops grown were in cotton, corn, soybean and rapeseed. Fifty-five percent of all cotton, 50% of soybeans, and 33% of corn grown in the U.S. in 1999 were transgenic varieties.[1] These large plantings stem from fairly straightforward manipulations of single genes, such as the transferring to corn and cotton genetic material from the bacterium *Bacillus thuringiensis* (Bt) which produces an insecticidal toxin or transferring to soybean, corn, cotton, sugar beets, and canola a gene with resistance to herbicides, such as glyphosate. The American farmer is perceived to be the beneficiary of lowered production costs primarily through better weed and pest control and a reduction in pesticide use with accompanying environmental improvement. Agro-chemical companies, who for the most part have spearheaded research and development of these crops, became involved because they foresaw a declining market for pesticides.[2]

Another area of promise widely discussed in the scientific and popular press is the improvement of food quality and composition resulting from genetic engineering. Because plants and plant products provide much of the world's food supply, it is only fitting that early applications of this technology be in this area. Recent estimates suggest that the market for transgenic seed has already reached several hundred million dollars per year and that more than 15 million hectares (37 million acres) were grown in the U.S. in 1998.[3] Concerns of risk to the food supply and environment that using transgenic methods present, although not always science based, have some merit and require careful scientific scrutiny.

Need for Biotechnology

The world population is growing by up to 160 people every minute with approximately 90% of them in developing countries. The world population is expected to increase from the current level of approximately 6 billion to more than 8 billion by the year 2050. Fewer people will be engaged in agriculture in both developed and developing countries. In the U.S., less than 1% of the population is engaged in primary agriculture, compared with 60% of the population in the early 1900s (U.S. Bureau of the Census). There will be less water per capita with the quality of the remaining water diminishing as demand increases. There will be less arable land for agriculture and less nonrenewable resources like phosphorus and potassium, which go into fertilizer. With agricultural inputs diminishing and food needs increasing, there is no option but to produce more food and other agricultural commodities from less arable land and irrigation water. The need for more food has to be met through higher yields per units of land, water, energy and time. Genetic modification technology could solve these problems with development of plants capable of producing higher yields of harvested produce per unit area and with less demand on the environment.

. Farmers have selected their preferred varieties based on characteristics demanded by consumers, such as yield, color, texture, and taste. These characteristics are not easily duplicated, even with the help of modern biotechnology. Fundamental to improving agricultural productivity are the genetic resources stored in gene banks around the world. The alleles represented in these stores are the evolutionary products needed for resistance and tolerance to diseases, pests, and harsh environments found in their natural habitats. A wider genetic base can be exploited using modern biotechnology to introduce genes from wild relatives into food plants. Alarming is the fact that many of these valuable genetic resources are essentially 'sitting on the shelf' in what has been term "gene morgues."[4] Hoisington et al., further observed that resource conservation only becomes important if the resource has or acquires recognized value.[4] Molecular techniques are being used to analyze genetic resources and to identify a wider range of genotypes for use in agriculture and food production.

Each biotechnology product emerging from research and development will have to provide a significant economic benefit to someone, such as increased yield, reduced input costs, reduced risk, improved product quality, or a new product or market niche; otherwise, it will not survive as a commercial product.[5] Better quality food products and increased efficiency in their production are major goals of commercial producers of transgenic crop seeds. According to Horsch, the most obvious benefit to the farmer will be lower total input costs which can be directly measured against current spending on agrochemicals that will be eliminated when using the improved crop varieties.[6] He further states that, whereas the price of seed will go up, the total cost of seed plus agrochemicals will go down, resulting in very real cost savings to farmers and that other measurable savings will accrue from reduced application costs such as fuel, time, and machinery use. Biotechnology allows genetic approaches that extend the possibilities available with conventional breeding or management approaches.

Transgenic Products

The seven principal transgenic crops grown in 1998 were soybean, corn/maize, cotton, rapeseed/canola, potato, squash, and papaya.[7] Biotechnology also makes possible the increased domestication of forests and fisheries, more efficient production of food crops and animal products, and expanded, nonagricultural uses of plants and animals.

Scientists have already produced transgenic livestock that serve as bioreactors, secreting human proteins in their milk for use as pharmaceuticals.[8,9] The technology has produced plants that offer promise of being cost effective agents of environmental remediation with genes that sequester metals; plants could be used to clean up soils contaminated with mercury, copper and other metals.[10] Several research groups are working to improve the salinity and drought tolerance of crops as more land becomes salinized and regional water shortages more prevalent.[11] Transgenic plants offer an important expression system for a range of recombinant proteins particularly those intended for therapeutic purposes and to produce vaccines against human diseases.[12,13]

Research is currently underway to establish methods of food enhancement to increase the content and bioavailability of essential trace metals[14] and vitamins.[15] Custom tailoring the chemical composition of lipids and other food components as a prevention of heart disease and cancer is also being studied.[16] Although most "first generation" transgenic products have specific agronomic traits designed to improve production efficiency, the next generation could be household, medical, industrial, and environmental products.[17]

We can expect modern biotechnology to reduce agricultural impact on the environment by reducing reliance on pesticides and applied nutrients. Genetic resistance to insects and fungi in crop plants could greatly reduce pesticide use.[18]

Risks to Humans and the Environment

Bacillus, a spore-forming, rod-shaped bacterial pathogen, is commonly used for insect control. Most insecticidal strains have been isolated from soil samples where the bacterium is ubiquitous. The microbial insecticides most widely used in the United States since the 1960s are preparations of *Bacillus thuringiensis* (Bt). Bacterial insecticides are not contact poisons and must be ingested by target insects to be effective. During development, bacterial cells usually produce a spore and a crystalline protein toxin—called an endotoxin. Crickmore et al., have recently classified the Bt δ-endotoxin family of related proteins into 24 major groups for which more than 140 genes have been described.[19,20] Most commercial Bt products contain the protein toxin and spores, but some contain only the toxin component. The different toxins composed of a single *Bacillus* species or subspecies have different specificities for different insect orders and may be active against an entire order of insects, or they may be effective against only one or a few species. After ingestion, the protoxin is activated by the alkaline environment of the gut and by proteolysis to produce the toxin. Hilder and Boulter describe the mechanism of Bt toxicity that begins with binding of the active toxin to glycoprotein receptors in the brush border membrane of susceptible insect's midgut epithelium.[21] After binding, the toxin rapidly and irreversibly inserts into the cell membrane which results in the formation of a pore which leads to epithelial lysis. Cell destruction causes gut paralysis. The insect is unable to feed and normally dies from starvation and/or septicemia (blood poisoning) within 1-3 days.

Bt is a naturally occurring pathogen that does not reproduce and easily degrades in the environment. A recent study found that the Bt Cry1Ab protein bioactivity, added to the soil as a component of Bt corn decreased with an estimated half life of 1.6 days and an estimated time to 90% degradation (DT_{90}) of 15 days.[22] Bt is rapidly killed when exposed to UV light. Upon decomposition of insects killed by Bt, bacterial spores are released into the soil where it can remain for about 4 months under suitable conditions.[23] The spores are readily inactivated at a soil pH of 5.1 or below.[24] In a review of studies submitted for registration of Bt Cry1Ab, senescent post-harvest corn plants containing the endotoxin were tilled into the top 6 inches of soil resulting in a maximum of 4.2×10^{-4} mg toxin/kg of soil.[25] Bt is classified as immobile because it does not move or leach once incorporated into soil. These findings demonstrate a lack of adverse effects to birds, aquatic invertebrates, honey bee larvae, coccinellid predators, and earthworms.

Horizontal gene transfer is the transfer of genes between organisms without reproduction. Nielsen and associates conducted a literature review and concluded that evolutionarily horizontal gene transfer events from plants to soil or plant-associated bacteria are rare and that horizontal gene transfer is more likely to occur between organisms that are more closely related in DNA sequence.[26] They further cautioned that their conclusions were based on the small number (n<10) of experimental studies found in the scientific literature.

There are a variety of ways to insert Bt toxins into plants. Bt genes can be incorporated into certain plant-dwelling bacteria where these altered bacteria grow and multiply within an inoculated host plant producing the Bt toxin. Genes coding Bt production of toxins have also been inserted directly into chromosomes of certain crop plants with the use of gene guns. Gene guns actually shoot microscopic tungsten or gold bullets coated with DNA into plant cells where some DNA gets into the cell chromosomes.

A major application of plant biotechnology is to make plants tolerant to specific herbicides. These products offer new weed-killing options to farmers in the form of herbicides that could not be used on nonengineered varieties. Most of these crops are being developed by, or in conjunction with, chemical companies who also sell the herbicides. In the United States in 1999, of the total 72 million acres (29 million hectares) planted with soybeans, half were planted with genetically modified herbicide-resistant seeds.[27] Use of herbicide-resistant seeds leads to easier weed control and less necessary tillage, hence, minimizing soil erosion.

Froyd lists several incentives for an agricultural chemical company to develop biological pesticides.[28] One incentive in the U.S. is time and money savings by registering a biological pesticide versus registration of a chemical pesticide. Registration costs of a chemical pesticide might be $10-12 million and take as long as 5-8 years whereas registration costs for a biological pesticide could be $1-2 million and take only

1-2 years. Registration of biological control agents does not require the high cost, long-term safety studies, such as carcinogenicity, plant and animal residues, and ecological fate and effects that are required for chemical pesticide approval. Another incentive is that fewer regulatory requirements translate into less time conducting required studies, hence, allowing faster product market entry and facilitate quicker investment recovery. New market opportunity is another incentive in which a biological establishes a new market segment in which none of a company's existing chemical pesticides are marketed.

The effect of engineered herbicide tolerance on agriculture chemical usage has been the topic of much heated debate. Proponents of herbicide-tolerant crops tout important environmental benefits and also state that farmers will be able to substitute newer, more environmentally friendly, herbicides for older more toxic ones. They concede that these crops will require continued use of chemicals but believe fewer herbicide applications will be needed. Those holding an opposing view believe that development of herbicide-resistant crops prolong agriculture's dependence on hazardous chemical inputs.

Several research groups have confirmed that genes introduced into some genetically improved crops spread into related native species.[29,30,31] Gene transfer is almost inevitable from crops that have infertile relatives in adjacent natural ecosystems. Genes have been migrating from conventionally bred crops to wild relatives for years. Genetically modified crops often contain genes derived from other phyla, introducing traits foreign to native plant populations. Accidental transfer of these traits into a wild population can negatively affect population dynamics between hybrids and native plants. Mutagenesis and embryo rescue (an example would be the excision of hybrid wheat x maize embryos from plant ovaries before desirable characteristics are lost or embryo death occurs) techniques used in conventional plant breeding also produce new genes in crops, about which little is known. Interestingly, these are often the very crops being used by organic farmers and being sold as natural foods.[32]

Most geneticists would argue that most foreign genes introduced into crop/native hybrids would in fact decrease their fitness in the wild, leading to rapid selection of these genes out of the population.[32] Proponents of terminator technology, designed to prevent germination of saved seed, argue that "escaping hybrids" would commit instant suicide and not spread into the natural world or to related species. Opposition to the terminator technology contends poor farmers need inexpensive, locally adapted seed that can be easily saved, not sterile seeds that must be repurchased every year.[33]

Genetic modification of plants to produce insect, fungus, and viral resistance could increase the fecundity of any resulting hybrids and lead to creation of aggressive weeds or plants that overwhelm wild populations. Herbicide tolerance to certain herbicides could also emerge resulting in weeds that would be difficult to control in agriculture, or in natural ecosystems like grasslands. More and greater damage to the environment could be the result of the mixtures of herbicides that will be needed to control them. Crop rotation that allows "rotation" of different weed-management practices or replacing the tolerant variety with one that reduces or eliminates any hazard are effective and well-established approaches of avoiding this type risk.[34]

Food chains dependent on insects feeding on wild plants could be disrupted if nontarget plants acquired insect resistance from genetically modified crops. Many insects depend on a single plant species for survival, thus gene flow to some wild varieties could be disastrous for some insect species. Acquisition of resistance in wild plants could also change their population dynamics, increasing the risks of them invading agricultural land and natural ecosystems. The potential for ecological damage also exists in plants with genetically modified virus and fungus resistance.

With the development of techniques for genetic manipulation of foods, a new risk for food-allergic patients is emerging.[35] Allergenic proteins from other foods introduced into foods that are generally tolerated, can induce allergic reactions in the allergic individual: consequently, genetically modified potatoes containing fish proteins (enabling storage below 0°C) may cause serious anaphylactic reactions in patients allergic to fish. Ninety percent of the documented food allergies world wide fall into eight foods or food groups (peanuts, soybeans, tree nuts, eggs, milk, fish, crustacea, wheat).[36] The potential allergenicity of a protein can be reasonably assessed only when the protein is known to trigger an immune response in sensitive subjects. The potential induction of an allergic response to a protein of unknown allergenicity cannot be easily predicted as no immunoserum of allergic subjects is available, necessitating a need for the design of an allergenicity assessment model for genetically engineered foods.[37]

An enormous amount of topsoil is lost as a result of plowing. According to the 1997 USDA SCS National Resources Inventory, cropland soil erosion continues to be a serious problem with topsoil eroding at the rate of 1.3 billion tons per year.[38] More than 60 million acres of fragile highly erodible cropland undergoes excessive erosion, and nearly 52 million acres of non-highly erodible cropland are determined to have erosion exceeding the tolerable soil loss rate. Excessive erosion of 1.3 billion tons per year leads to concerns about sediments, nutrients, and pesticides impacting water and air quality, as well as reducing the capacity of the land to grow food sustainably. Transgenic weed management systems could reduce the need to disturb the soil by plowing.

A Word of Caution

The Irish Famine caused approximately 1.2 million deaths and 315 thousand averted births from a population of 8.5 million in the six years from 1845 to 1851.[39] In terms of mortality, this was the fourth worst devastating famine in history being eclipsed only by those famines occurring in China 1957-62, in Bengal in 1943, and in the Ukraine in the 1930s.

This tragedy was the result of the near total devastation of the Irish potato crop by the spore spreading fungus, *Phytophthora infestans*. The potato, high yielding and high in nutritional value, was the staple of the poor Irish tenant farmer with consumption ranging as high as 6.350 kg daily by agricultural laborers when potatoes were available. The potato could also be grown on land where no other crop could survive.

A modern day scenario similar to this is not as farfetched as it might sound. The current practice of planting millions of acres in genetically uniform varieties has made U.S. agriculture extraordinarily vulnerable to pests. An invasion by a resistant pest could wipe out an entire crop. In the event of such a catastrophe, scientists will focus on other cultivars and wild populations for resistance traits. If too many of the small populations become extinct, agricultural breeders may not be able to find the resistance trait needed to save the crop.

Such an event happened in 1970, when the U.S. corn crop in the South and Corn Belt was devastated in a few short months by a single fungus.[40] The fungus, which caused a disease called the southern corn leaf blight, was able to move swiftly from one cornfield to another because almost all the corn was susceptible. The quest for high yields had led farmers to rely on a few genetically uniform cultivars of corn, which were susceptible to the disease. No pesticide saved the day. Resistance had to be found either in other corn cultivars or wild corn relatives. Breeders found the resistance genes in the 1970s.

Conclusion

Biotechnology, through the use of gene cloning, gene splicing, and gene transfer technologies, has created a vast potential gene pool. The vast and diverse number of species of plants and other organisms of the world is one of the most important sources of beneficial genes for crop improvement Essential to the location and utilization of these genes is understanding how they work or screening for biological specificity. This valuable resource, the potential gene pool, is being destroyed worldwide at an alarming rate through overgrazing, slash and burn agriculture, desertification, urbanization, and damaging environmental practices. Large amounts of natural habitat are destroyed annually with the permanent loss of some species before the genetic value can be evaluated and preserved.

The sad paradox is that the effective use of biodiversity on earth is one of the most important means of protecting it. Biotechnology can enhance agricultural productivity and can provide means of preventing and removing environmental threats and pollution. The best protection for natural habitat is increased yields for existing cropland. If sufficient yields were attainable with present agricultural acreage, less natural habitat would need to be cleared and plowed.

Genetically engineered resistance to insects and diseases will also, with appropriate agricultural management practices, reduce the need for chemical pesticide applications, avoiding the risk of worker exposure, food residues, and soil and ground water contamination. Incorporation of the Bt protein into cotton and corn has reduced the application of specific, highly toxic pesticides in the U.S. by more than 80%.[41] Savings in the high cost of equipment fuels as well as equipment wear and tear will be gained with the reduction of pesticide application. The consumer will be the beneficiary of decreases in production costs with continued low food costs and increased abundance and greater availability of diverse types of foods that have a better quality and appearance.

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