Biotechnology: Exploring the Science of GMO's

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ABSTRACT:

In recent years, genetically modified organisms have come under scrutiny in relation to the human food supply. The use of genetic manipulation, however, is not new in the area of plant and animal breeding. Techniques such as selective breeding, inbreeding, hybridization, recessive trait breeding, and mutagenesis have been used for centuries. Genetically modified crop species benefit the producer by providing effective and efficient pest control. At the same time, these genetically engineered plants can reduce chemical and fossil fuel use, reducing the impact of agriculture on the environment. Some possible negative effects of this biotechnology include out-crossing of pollen to closely related weed species, or non-GMO crops. To date there is no scientific evidence to suggest that GMO foods represent a health risk to humans or livestock, or poses an unmanageable risk to the environment. Genetically modified foods are held to the same high standards for nutrition and safety as all foodstuffs.

(Key Words: genetically modified organisms, bioengineering, agriculture, genetic manipulation, environment, food safety issues)

INTRODUCTION:

Biotechnology encompasses a broad range of technologically and biologically based scientific disciplines. Simply put, the term refers to any technology with a biological basis. The word biotechnology can be applied to everything from gene splicing and hybridization to bio-pesticides. Recently however, the many fields of biotechnology have been collectively scrutinized for advances in genetic engineering.

The term biotechnology has been used broadly to describe all genetic modification, particularly in the field of agriculture. At the same time transgenics, which are a specific type of biotechnology, have been given the title of "GMO" or genetically modified organisms. The purpose of this paper is to explore and clarify the GMO issue in modern agriculture. To this end, this issue paper will discuss the various methods of producing genetically modified organisms, and how they work, as well as the benefits and potential risks this technology poses for humans and the environment.

Tampering with nature to produce genetically altered life forms is an integral part of human history. Farmers and scientists in search of desirable crop and animal traits have modified virtually every human food source from its original unaltered state. Plants and animals produced by modern agriculture today are the result of more than 10,000 years of some level of genetic modification and refinement (Acquaah 2000). Despite this long history of domestication, selection, and controlled breeding, there is a perception that biotechnology is somehow new or radical (Feed Magazine 2000).

DNA (deoxyribonucleic acid) is the universal genetic code for inheritance in all living things. Within DNA are genes, which represent a code for the synthesis of a particular protein. The proteins produced are called gene products. Of critical importance to biotechnology is the fact that most genes do not have characteristics specific to the organism in which they are found (Feed Magazine 2000, IFT 2000). In other words, it is generally impossible to determine the specific organism from which a gene arises simply by examining the gene sequence alone. The uniqueness of an organism lies not only in the DNA sequences of its genes, but also in the organization of the genes present, their timing, and extent to which they are expressed (IFT 2000). Often identical genes are found in organisms that are only remotely related.

Traditionally, biotechnology was limited to the mixing of genetic material through the reproductive process (Feed Magazine 2000, IFT 2000). This crossbreeding or cross-pollination within or among closely related species involves selecting from the desired genetic traits that already exist within the gene pool of the species. Technically known as hybridization, the resulting offspring are usually sterile but possess traits superior to either inbred parent (Campbell 1990). This conventional crossbreeding requires countless random combinations of genes in the hopes of producing one or more of the desirable traits in offspring generations. One of the greatest limitations to these traditional techniques is that genetic transfer is not possible between completely different species because of genetic incompatibility (Feed Magazine 2000, IFT 2000).

Another form of traditional genetic manipulation involves the use of inbreeding or backcrossing in order to strengthen the expression of a recessive genetic trait (Campbell 1990). This process can be complicated, extremely time consuming, and unreliable. Inbreeding tends not only to strengthen desirable traits, but undesirable ones as well, particularly when they are dominant. These undesirable traits must be removed through selection in the next several generations of progeny (IFT 2000). Selective breeding of this kind may also be complicated by the need for simultaneous expression of many recessive alleles in order to produce the desired trait.

Because the amount of DNA involved is so great and the selection of genes in the target organism cannot be precisely controlled; traditional, conventional methods are far less effective and predictable than rDNA biotechnology methods. Recombinant DNA (rDNA) is two pieces of DNA from different organisms that have been joined to form a single piece of DNA. The term recombinant DNA also describes the natural recombination of DNA from two parent organisms during sexual reproduction.

Through recombinant DNA technology, specific plant characteristics can be precisely identified, characterized, enhanced, and transferred with appropriate individual genes rather than through the transfer of uncontrolled and randomly assorted groups of genes. This precision reduces the chance of undesirable effects, and greatly increases the diversity of useful genes that can be incorporated (IFT 2000).

Transgenic plants contain a gene or genes, which have been artificially inserted instead of the plant acquiring them through pollination. The inserted gene or gene sequence, known as a transgene, may come from another plant, or a completely different species (Colorado State 2000). Using transgenes, plant breeders try to assemble a combination of genes in a plant, which will make it as useful and productive as possible for the desired application. This enables plant breeders to bring together in a single plant useful genes from a wide range of living sources.

This technology also provides the means for identifying and isolating genes controlling specific characteristics in one kind of organism, and for moving copies of those genes into different organisms (Colorado State 2000). All this is possible because the DNA of all life is made of a unique arrangement of the same four nucleotides. This precise scientific approach still allows for the generation of more useful and productive crop varieties containing new combinations of genes, but expands the possibilities beyond the limitations imposed by traditional methods (IFT 2000).

Recombinant DNA techniques use restriction enzymes to cut the DNA strands at specific locations and select the required genes. These genes are then typically inserted into circular pieces of DNA from bacteria, called plasmids. During the normal reproduction process of the bacteria, clones of the inserted gene are produced and passed on to the next generation. The genetic material contained in the plasmid can then be introduced into a plant using a bacterium virus to infect and carry the gene to the plant's DNA. Entrance into the plant cells can also be achieved by Electro-Poration and Chemical Poration methods. These methods create holes in the cell membrane, which allow entry of the new genes (Feed Magazine 2000).

Bioballistics is another method of gene introduction. It generally involves a projectile method that uses metal slivers coated with genetic material to deliver genes to the interior of the cell. The slivers pass through a perforated metal plate into the living cell, where the genetic material enters the nucleus and incorporates itself into the host genes (Feed Magazine 2000).

Yet another method, called Microinjection, involves the direct injection of genetic material containing the new gene into the recipient cell using a needle. This is currently the most often used method for producing genetically engineered organisms (Feed Magazine 2000).

ANALYSIS OF THE USE AND BENEFITS OF GMO CROPS:

In order to understand how transgenic or genetically modified plants work, it is important to have some understanding of how pesticides affect plants. Herbicides, fungicides, and insecticides all work in the same way, by acting on target sites in specific target organisms. Herbicides have particular target sites in the plant, which they bind to and inhibit. The most frequent target sites are enzymes, however some herbicides use non-enzymatic target sites. Most herbicides are very specific and inhibit only one enzyme or target site in cells containing thousands of enzymes. In binding to an enzymatic target site, the herbicide stops or slows down an important enzyme function, which causes death in the cell. Some herbicides interfere with the chemical pathway involved in photosynthesis and either block electron transport in Photosystem (II) or accept electrons from Photosystem (I) resulting in high-energy toxic compounds that destroy membranes and lead to plant death. Others mimic hormones or disrupt cell division resulting in dysfunction, abnormal growth, and death (Hall 1996).

Most herbicides, like other types of pesticides, are selective based on metabolism. This means that they affect species that do not have the ability to metabolize them and make them harmless. It also means that for a species to be affected, it must possess the necessary target sites. Some herbicides like the glyphosate type are not selective and affect most kinds of plants. Still others known as proherbicides are metabolized into the active form within the plant. Following metabolism in plants, herbicides are frequently conjugated to sugars or amino acids. It is believed that these forms of herbicide are non-toxic and move to the cell vacuole (Hall 1996).

Most common genetically engineered crops contain modifications that make the plant resistant to certain diseases, tolerant to certain herbicides, or allow them to produce their own pesticides, thereby eliminating or reducing the need to spray. Transgenic plants are simply plants which have been given the genetic ability to metabolize or produce certain chemicals. These kinds of plants are often referred to as GMO's, genetically modified, herbicide tolerant, or insect resistant depending on the imposed trait. It is important to note here that all crop species are naturally herbicide tolerant to at least some selective herbicides. For example, wheat will not die if exposed to recommended rates of the herbicide 2,4,D however, canola will die. The same is true of herbicide tolerant plants, which can also be injured or killed if the herbicides assigned to them are used incorrectly (Feed Magazine 2000).

Weed control is one of the greatest challenges in crop production because poor weed control results in lower yield and quality. Many herbicides control only certain weed species, and are approved for use on certain crop species at specific growth stages. Staging is very difficult because not only must the crop be at the appropriate stage to avoid injury, the weeds must be at the right stage for effective control. Some herbicides have a characteristic known as "carry over" in which residues persist in the soil for extended time periods. In one way this is beneficial because it extends weed control beyond the application growth stage, but it may also injure subsequent susceptible crops (Hall 1996).

Herbicide tolerant crops such as canola and soybean resolve many of these problems because they have transgenes providing tolerance to specific broad-spectrum herbicides like glyphosate (trade name: Roundup). This means that a single herbicide can be applied to a tolerant crop at any stage of development and achieve control of most if not all weeds. Early weed control is of critical importance to crop establishment because the crop is not competitive at emergence. Herbicide tolerance removes the necessity for weed staging while avoiding crop injury and the necessity for multiple applications. This flexibility allows for subsequent applications but often high levels of weed control are only required during the early stages of crop development. Another benefit is that these types of broad-spectrum herbicides degrade rapidly in the soil, eliminating "carry over" and reducing environmental impact (Pioneer 2000).

"Bt" is short for *Bacillus thuringiensis*, a common soil bacterium whose spores contain a crystalline (Cry) protein. In the insect gut, this protein breaks down to release a toxin known as delta-endotoxin. This toxin binds to the intestinal lining creating pores, which result in ion imbalance, paralysis of the digestive system, and eventual death.

Several different versions of Cry genes or Bt genes have been identified. They are effective against different orders of insects or affect the gut in slightly different ways. CryIA(a), CryIA(b), CryIA(c), Cry1B, Cry1C, Cry1D, CryII and CryIV are effective against Lepidoptera. CryII and CryIV affect Diptera while CryIII and CryIV affect Coleoptera (Colorado State 2000).

The use of Bt to control insects is not new. Insecticides containing Bt and its toxins have been used for many years. Bt based insecticides are considered safe for mammals and birds, and safer for non-target insects than conventional products. What is new, however, is that a modified version of the bacterial Cry gene has been incorporated into some crop species' DNA so that these plants can now produce the toxin themselves. Currently these crop types include varieties of corn, cotton, and potato (Colorado State 2000).

The use of Bt crop varieties has dramatically reduced the amount of chemical pesticides applied to cotton. In the United States, farmers used 450,000 kg less pesticide on Bt cotton than would have been used on conventional varieties in 1998 alone. Bt genes have proven to be very effective in the short term for protecting against crop insect damage, as well as reducing fungal contamination in corn (Feed Magazine 2000).

Other benefits to the use of genetically modified plants include improved nutrient content. An example of this can be found in the new development of Golden Rice, bioengineered to provide dietary beta-carotene. It has also been demonstrated using varieties of tomatoes and peanuts that biotechnology can reduce food costs and extend shelf life through genetic manipulation (Feed Magazine 2000).

From an environmental perspective, biotechnology can make agriculture less environmentally intrusive. Modern agriculture is both resource intensive and output orientated. Large amounts of fertilizer and pesticides are typically used to generate acceptable yields per unit of land. These amounts are significant and can affect natural resources such as ground and surface water (Acquaah 2000). Biotechnology crops can have the ability to absorb more available nutrients, or be drought resistant reducing the need for irrigation. They enable the use of environmentally benign herbicides, increase the flexibility of crop rotations, and facilitate no-till agriculture; which reduces fossil fuel use, soil erosion, and air pollution (Acquaah 2000). These crops are also more efficient; they produce higher yield per unit land. According to the World Bank, biotechnology could boost food productivity in the developing world by 25 percent, feeding more people and consuming fewer resources (Wallach 2000).

DISCUSSION OF POTENTIAL RISKS:

All of the benefits outlined above are not without the presentation of some level of risk. It is a well-known fact that the introduction of a new species into a new environment is risky and can create a multitude of problems. These same risks accompany the introduction of new genes into a new species. In the case of GMO technology, the issues are further complicated by concerns regarding the safety of the food supply.

One concern often expressed is the belief that rDNA technology derived food can create antibiotic resistant bacteria. The use of antibiotic resistance is a common laboratory technique employed to easily and effectively identify the presence and expression of desirable genes. This is achieved by marker assisted breeding whereby the desired gene is accompanied by a marker gene, such as antibiotic resistance. The use of antibiotic genes, leading to a transfer of antibiotic resistance and reduced efficacy of antibiotics in human populations would require a series of highly unlikely events.

Numerous scientific bodies have concluded that the antibiotic resistance markers used in rDNA biotechnology derived foods to date, do not present a significant food safety concern. Currently, to eliminate any potential risk, new rDNA biotechnology techniques use marker genes unrelated to antibiotic resistance. One current technique is to use the GFP gene, which makes the plant fluoresce when placed under UV light. Another technique is to mark the transgene with a gene expressed as a specific, obvious, phenotypic trait such as the absence of a normal part or color change (Colorado State 2000).

Another concern often expressed is the possibility that biotechnology derived plants can damage the environment. Currently evidence indicates that rDNA technology has numerous environmental benefits with significant negative impacts (IFT 2000). A careful review of the scientific evidence has found no increased adverse environmental or ecological effects inherently attributed to the use of rDNA biotechnology in food production (IFT 2000). Concerns about monoculture and genetic diversity, pollen drift, the creation of “super weeds”, and pesticide resistant insects are generally not unique to GMO crops (Colorado State 2000, Pioneer 2000).

With respect to the pollen drift issue, the available evidence suggests that there is minimal possibility of pollen mixing from GMO crops. A recent study completed at the University of Maine found that cross-pollination of conventional corn by transgenic corn in an adjacent plot was 1% at a distance of 100 feet and declined to zero at a distance of 1000 feet (Colorado State 2000). This suggests that it is possible to prevent the transfer of transgenes to non-transgenic varieties by following the same recommended planting distances currently in place to maintain purity in conventional varieties (Colorado State 2000, Pioneer 2000).

It is important to note, however, that the degree of pollen transfer is highly variable. There are a number of factors, which can assist pollen transfer. The pollen load in a field is usually great enough to prohibit significant levels of outside pollen (Pioneer 20000). In addition, in a dominant gene system, such as that used to produce hybrids with the Bt gene, only half the pollen in the field contains the Bt gene (Pioneer 2000). Additionally, pollination timing typically varies from field to field, depending on planting date, maturity, and weather. Pollen travel also depends on environmental factors such as wind vectors, temperature, and humidity (Pioneer 2000). Different plant species also employ different pollination strategies. For instance *Brassica napus* (argentine canola) uses a system of self-pollination, which means that the required pollen can come from the same flower. For this reason, argentine canola produces almost no out-crossing even within the same field. *Brassica rapa* (polish canola) on the other hand, is self-incompatible and so must out-cross with other plants. It is with species like the latter that a risk of transgene movement into closely related weed species occurs.

The risk of so called “super weeds” is possible where transgenic crops containing a herbicide tolerance gene grow close to related weed species such as wild mustards in canola and jointed goatgrass in wheat. Gene transfer from crop to weed through pollen transfer has been demonstrated in both of these crops (Colorado State 2000). It is important to note that while this gene transfer may make the weed species tolerant to a specific herbicide, the weed is still susceptible to others and so can be controlled with herbicides in the same way as volunteer crop species. One possible solution to this problem is to link herbicide tolerance genes to other genes controlling seed dormancy or flowering (Colorado State 2000). This would prevent any weed species from transferring transgene traits to subsequent generations.

For herbicides to be effective, they must be applied at the proper time and at the proper amount. To date, most weed resistance problems are the result of improper herbicide use not transgenic pollen transfer. The more the same chemical or chemical group is applied to any given field, the greater the risk of developing weed resistance. Reduced, off label application rates also increase the likelihood of resistance by allowing some sprayed weeds to survive and pass on their hardiness (Hall 1996).

Nature has shown that biocide resistance in bacteria and plants can develop over time. The risk that insects can become resistant to insecticides also exists. A major concern is that widespread planting of transgenic crops containing the Bt gene will accelerate the development of Bt resistance in pest populations. Bt resistance has been demonstrated in the diamondback moth in the United States and Asia. However, this is not the result of the Bt gene, but rather many years of spraying Bt as an insecticidal spray. Decreased susceptibility to Bt has recently been documented in soybean loopers collected from Bt cotton, indicating that resistance can develop from exposure to transgenic crops. It is hoped that the use of “refuge” or non-transgenic areas can prevent or slow the development of Bt resistance (Colorado State 2000).

Another environmental concern dealing with biotechnology and insects involves the monarch butterfly. Two preliminary studies recently concluded that significant monarch mortality was related to consuming large quantities of Bt corn pollen. Subsequent analysis has indicated that the design and methods of the first two initial studies were flawed. The only valid conclusion that can be derived, based on the preliminary studies, is that if force-fed large quantities of Bt corn pollen, monarch caterpillars die. It should be noted that corn pollen is not a natural food source for monarch caterpillars, and if other food sources are available they will not eat it (IFT 2000). Since the release of these initial studies, the bulk of the scientific evidence indicates that the impact of pest resistant crops on monarch butterflies is minimal. It has been reported that monarch populations increased by 30% in 1998 and 1999, along with a 40% increase in Bt corn acres (Pioneer 2000).

With the effectiveness and selectivity of biotechnology, concerns have been raised that transgenic crops will reduce biodiversity (IFT 2000, Pioneer 2000). The fear is that GMO crops will replace traditional or indigenous crop varieties, especially in developing countries. While this risk is real, it is not a risk that is limited to transgenic crops. What is needed is better conservation of traditional crop varieties so that their genetic diversity can be preserved and utilized (IFT 2000).

Perhaps the biggest concern related to GMO crops deals with food safety and the associated risks from bioengineered food products. One real concern is that biotechnology derived food can cause new allergies in human populations. To date no unique allergic reactions have occurred through the use of rDNA technology. The proteins that have been introduced into bioengineered foods to confer insect resistance and herbicide tolerance traits are unlikely to be allergens because they are expressed at very low levels in the modified food, they are not structurally similar to known allergens, and they are readily digested by the human gastrointestinal system (IFT 2000).

CONCLUSIONS:

Feed performance studies have confirmed that rDNA products are nutritionally equivalent to conventional varieties (Pioneer 2000). There is no available evidence to support the belief that genetically engineered foods currently approved for use are toxic to humans or that released bioengineered organisms are likely to proliferate in the environment (Feed Magazine 2000). Likewise, there is currently no evidence to support the notion that consuming genetically modified organisms will result in tumors or abnormalities that can be passed up the food chain. This is because the digestive systems of animals break down the rDNA just like the DNA of any other food source (IFT 2000).

Recently, The National Academy of Sciences has stated that there is no scientific evidence to suggest that bioengineered or transgenic foods are unsafe (Feed Magazine 2000). However, specific engineered organisms may be harmful by virtue of the novel traits they possess. This means that the risks of individual genetically engineered organisms can differ greatly, depending on the particular gene-organism combination, and must therefore be evaluated on a case-by-case basis (Pioneer 2000).

It is therefore the responsibility of legislators, policy makers, and manufacturers, to continue to ensure that biotech foods are subject to the same rigorous standards as their conventional counterparts. Issues such as the potential development of allergies to new proteins and pollen drift from rDNA biotechnology derived crops must continue to be evaluated. It is likely that in the future, new developments in rDNA biotechnology can solve intractable pest problems, help protect the environment, and lower costs to consumers while ensuring the food supply. Further research may one day enable the use of vaccines produced in foods like bananas or potatoes, foods with improved nutritional composition to meet specific needs of different populations like Golden Rice, and functional foods that produce specific plant components or synthetic drugs recognized for their ability to prevent disease.

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