BIOTECHNOLOGY FOR THE AGRICULTURE AND FOOD PROCESSING INDUSTRIES

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ABSTRACT

Biotechnology has created a great deal of excitement in the past decade because of its potential for revolutionizing the development of new medical, agricultural, and food products. Some of the areas which will use biotechnology are: food ingredients, starter cultures, nutritional quality of foods, inactivation of specific plant enzymes, transgenic animals, and biosensors. However, the public is uneasy because of the possibility for unscrupulous individuals or companies to exploit the technology for increased profits without regard for social or environmental costs. One example of this is the legal difficulties faced by companies trying to bring the hormone BST to market in the US and Europe. The biotechnology industry needs to respond to these fears in ways that help create an understanding of the technology and open communications about it between the companies using it and the public.

INTRODUCTION

Over the past several years there has been a tremendous amount of excitement about biotechnology and what it can do to change the way in which people live. Biotechnology in broad terms can be defined as "all of the industrial processes that use biological systems". In this definition, a biological system means "plants, animals, microorganisms, or any part of these living creatures" (Harlander, 1991). This definition can include relatively new technologies such as genetic engineering as well as more traditional activities such as plant and animal breeding, agriculture, and food processing.

The nucleus of every animal and plant cell contains compounds that can be thought of as "records of inheritance". These compounds are called chromosomes and are made of material called DNA. Pieces of DNA form genes which contain codes necessary for producing proteins (especially enzymes). The code on the genes is a sequence of four chemical bases which produces an amino acid and a series of chemical base codes will produce a series of amino acids. These series of amino acid make up a particular protein (or enzyme).

When most people talk about "biotechnology" what they are generally referring to is genetic engineering. This is a group of related technologies that allow researchers in laboratories to manipulate the genetic material of plants, animals, and microorganisms with greater precision, predictibility, and more control in less time than is necessary for more traditional methods of genetic manipulation in fields and greenhouses. These traditional methods have been used for thousands of years to give plants and animals desirable characteristics. In most cases, the improvements are the result of breeding between varieties found in the wild and previously domesticated varieties and are usually between varieties of the same species. The methods traditionally used involve the shuffling of genes by breeding the parents and then selection of the offspring with the desired traits. Because of the large number of gene combinations possible, several crosses must be made to obtain the required traits. This process requires a great deal of time; sometimes as much as 20 years are needed to produce improved plant or animal varieties. To understand why, consider what happens when two individuals with one gene that is different are bred together. The number of different ways that this one gene can combine is 3n where n is the number of genes involved. If the parents differ in 10 genes (a very small number), 59,049 gene combinations are possible; while if the difference is 20 genes, the number is about 3.5 billion possible gene types. Thus, when plants or animals are bred, a tremendous amount of combining and recombining of genes occurs.

With genetic engineering, the genes that produce desirable characteristics can be identified and those particular genes can be inserted into the chromosomes of the plant or animal to give the desired characteristics. This allows researchers to transfer single genes in a precise, predictable, and controllable manner rather than having to combine all of the genes from one particular organism with all of the genes from the other organism, giving highly unpredictable results.

This new technology has created a tremendous amount of excitement in the US pharmaceutical and food industries. According to the US Department of Agriculture, as of 1992, 450 permits for 24 different genetically engineered crops and 3 microorganisms had been issued and completed at 1000 sites in 41 US states and Puerto Rico (Medley, T., as quoted in Harlander, 1993).

PRODUCTS OF GENETIC ENGINEERING ALREADY IN THE MARKET

Already the products of genetic engineering have entered the marketplace. One of the first entered in 1982 when human insulin produced by bacteria containing the human genes encoding for insulin was introduced. Insulin is a protein hormone needed daily by people with the disease diabetes. Previously, all of the insulin available was extracted from the pancreas glands of butchered cattle and pigs using a long and expensive process. The human insulin produced by the bacteria is still expensive but is less than the porcine or bovine insulin, the available supply is larger, and the insulin is more suitable for people who are allergic to the animal insulin.

Another protein hormone that has recently entered the market is Bovine Somatotropin (BST). About 50 years ago, Russian scientists discovered that BST could be extracted from the pituitary gland of dead cattle and injected into live cattle and thereby increasing the milk yield by as much as 40%. However, it was impossible to produce enough BST to make it commercially practical to use until the late 1970's when the gene that encodes for BST was genetically engineered into microorganisms. BST was recently approved for commercial use in the US.

In 1992, a US patent was issued to DNA Plant Technologies, Inc. for antifreeze proteins that helped suppress ice crystal growth. These proteins were cloned (produced by a method that made an identical copy) from proteins that occur naturally in arctic fish where they help protect blood serum from freezing. They function by binding to the surface of expanding ice crystals, thus inhibiting further growth. In its application, DNA Plant foresaw use of these proteins in the following areas:

1. Preservation of the texture of fresh produce through repeated freezing and thawing.

2. Preservation of the smooth texture of ice cream and similar frozen dessert products.

3. Extension of the shelf-life of frozen bread doughs.

DNA Plant reported that these proteins were "the first in (its) portfolio relating to the use of antifreeze protein technology. Other products are pending."

DNA Plant has announced that in 1994 it will introduce a tomato that has a 3 to 4 month shelf-life. They can achieve this by inactivating the gene that causes ethylene production. The production of this chemical by the plant begins the processes that lead to rotting.

FUTURE PRODUCTS OF GENETIC ENGINEERING

The types of genetic engineering products that will effect foods and drugs in the future fall into several catagories (Harlander, 1991; Harlander, 1993):

1. Food Ingredients

Many microbially-derived compounds can be used as food ingredients. These include vitamins, sweetners, amino acids, stabilizers, thickeners, colors, flavors, flavor enhancers, and enzymes. These could be supplied more consistently and reliably and at lower cost if produced by genetically engineered microorganisms.

2. Starter Cultures

These are bacteria, yeasts, and molds that are used to produce fermented foods such as cheese, yogurt, sausage, pickles, sauerkraut, wine, beer, fish sauce and soy sauce, and bread. Genetic engineering can be used to improve the metabolic properties of these microorganisms.

3. Nutritional Quality

The nutritional quality of foods can be improved using genetic engineering. The enzymes in oilseeds such as soybeans, can be altered to produce "healthy" oils that are more unsaturated (i.e. contain less hydrogen atoms). Consumption of fats and oils high in saturation has been linked to increased risk of heart disease. This development could have a tremendous impact on the agriculture industry in tropical countries such as Thailand which produce large amounts of highly saturated coconut and palm oils. The high amount of saturation makes it difficult to sell in overseas markets where the consumer is very health conscious. Other ways that genetic engineering can improve the nutritional status of foods are: 1. increasing the amounts of essential amino acids in grains, 2. increasing fiber content, 3. improving the taste, texture, color, and processing characteristics of agricultural commodities, 4. increasing the amounts of vitamins, minerals, etc. known to have therapeutic value.

4. Inactivation of Specific Enzymes

Many enzymes in plants, animals, and microorganisms produce effects that considered undesirable by the food industry. Through the use of "antisense" technology, specific enzymes in a plant can be inactivated. In very simple terms, antisense genes are those which have a structure that is a mirror image of that normally found in a cell. When these "mirror" images are put into a plant, production of the unwanted enzyme is slowed. This same "antisense" technology could be used to inactivate the enzymes responsible for producing toxicants in foods. For example, it could be used to reduce or eliminate the caffeine in coffee beans. This is the technique that DNA Plant is using for its long-life tomato.

5. Production Agriculture

Genetic engineering has been used to introduce genes into plants to make them more resistant to insects, viruses, and diseases. It can also produce plants that tolerate extreme temperatures or high salinity (another increasing concern in Thailand with the large decrease in available fresh water supplies). Making plants more disease and/or insect resistant could decrease the use of agricultural chemicals for pest control. However, recent evidence indicates that insects can become resistant to the chemicals produced by genes introduced into plants to confer a natural resistance to insects. This happens in much the same way insects can become resistant to chemical pesticides.

6. Transgenic Animals

Many pharmacuetical products are currently made by microorganisms; by using animals to produce these products, much larger quantities at a lower cost can be produced. For example, the gene that encodes for the enzyme that dissolves the blood clots found in human heart attack victims has been put into sheep. The sheep then excrete the enzyme in their milk from which it can extracted. Pigs have been genetically engineered to produce human hemoglobin in their blood. This hemoglobin can be purified after the pigs are slaughtered and used as a human blood substitute. This procedure is still not used commercially because thousands of pigs must be used to provide sufficient quantitites of hemoglobin. For it to be economically feasible, the meat from the slaughtered pigs must be sold as well as the blood.

7. Biosensors

The reactions of enzymes are highly specific, meaning that they work on only a few types of molecules (usually one type only). Because of this, enzymes or an entire microorganism can be used to measure the concentration of a specific substance in a complex mixture. The enzymes (or microorganisms) are immobilized onto solid surfaces and the reactions between the substances and the enzymes can be detected electrochemically, photometrically, thermometrically, or mechanically. In theory, the enzymes could be used for continuous monitoring of substance levels in a process stream. This would avoid the sometimes long and tedious wet chemical analytical methods that are currently used. Unfortunately, one of the biggest drawbacks at present is that the senors are easily contaminated and it is very difficult to recondition them for reuse.

DISTRUST OF BIOTECHNOLOGY: 'FRANKENFOOD'

To people in the biotechnology industry and to the people in the industries that make use of the products of biotechnology, this has seemed like the wave of the future. Scientists and industry managers have talked in glowing terms about how such things as "genetic engineering", "growth hormones", "genetically-modified organisms", or "gene technology" can change and improve the lives of people around the world. To the technically trained, these phrases are both descriptive and scientifically valid. However, the consuming public does not understand these phrases and generally has reacted negatively to them. The industry needs to explain what it is doing and the benefits and risks associated with its activities. One example of this is the story that appeared in the New York Times (June 28, 1992) headlined "Geneticists Latest Discovery: Public Fear of 'Frankenfood'. This was a report on the 1992 US Institute of Food Technologists convention and focussed on the genetically engineered foods that were displayed by the various processors there. The main theme of the article was that "deconstruction and reconstruction of DNA in edible plants and animals seems to tap a well-spring of misgiving". This article discussed the possibilities for genetic engineering: it could help safeguard against food-borne disease, curtail dependence on chemical pesticides, and increase food production.

The article went on to say "but world hunger seemed far removed from the IFT convention where displays about low-fat sausages and dips and ice cream and hamburgers with simulated fats seemed to predominate". One sales representative was quoted as saying "they've been talking about famine for 50 years". He noted that "the food industry was a consumer industry and not a philanthropy". The reporter then added the comment that it was a business driven by people willing to pay premium prices for low-fat hot dogs.

It was noted that the most discussed product at the show was the tomato that was made frost-resistant by adding the gene from arctic fish as discussed earlier. This was being promoted as a way of preventing crop losses. Dr. Dietrich Knorr a biotechnology researcher in Germany was quoted as .saying "Makers of tomato sauce and ketchup are more interested in pulp than antifreeze characteristics. By increasing the amount of solid material in a tomato by 1%, the profits of tomato processors world-wide would increase by US$100 million per year. Personally, I have to fear that people or companies will use the technology to over-express certain properties (of plants or animals in order to increase profits)."

Dr. Pernet of the Roquette Corporation who is experimenting with genetic engineering of carbohydrates (sweetners) expressed many of the same concerns. He noted that the public is most worried about allergic reactions to genetically altered food and the long-term health implications of consuming it. Dr. Pernet did not feel this was a problem: "out of the hundreds of genes in an organism, very few are potential allergens and all of those are well known." He noted that "the point of most technology is control: cost control and quality control. All of us (researchers) know we can control several generations of genes but no one has any idea over how many generations that control will work or how long it will take for the genes to resist control. And that's scary." This resistance can already be seen in the resistance that many organisms have to various pesticides, herbicides, and antibiotics. This resistance is caused by changes in the genetic structures of the organisms that enable them to resist the effects of these chemicals.

If two "experts" in the field can express reservations such as these about biotechnology, is it any wonder that the public which understands very little about it is so fearful of it? If the public receives the impression from the press that the industry is out to make money regardless of the consequences to society, is it any wonder that they want the technology severely restricted so that any damage is limited?

COMMUNICATING THE BENEFITS OF BIOTECHNOLOGY TO THE PUBLIC

A classic example of what can happen to biotechnology if the public does not understand it is that of BST. The gene that encodes for BST in cattle was genetically engineered into micro-organisms in the late 1970's and soon became available for researchers to experiment with. They found that it would significantly increase milk yields and the results were reported at a scientific conference. A technical journal published a report on the conference which included the reported results. From this report, the results were reported in the agricultural press in both the US and Great Britain. When reporters from the popular press found out about BST, they started asking for information from both government officials and company representatives. They were "met by a wall of silence" (Griffen, 1993). This left journalists to write their own stories and draw their own conclusions.

The press now had a story about how milk yields from cows were going to be increased by up to 40% by injecting them with something called a "genetically-engineered hormone". The experiments on this were a secret and the milk produced by it was going into the milk supply where it would be indistinguishable from milk produced by more "natural" methods. The press and consumer advocates felt that the public had a "right-to-know" if their milk was produced using this substance. The BST story "generated more than 4000 articles on the subject, 24 hours of television coverage, and about the same amount of radio coverage in an 18 month period (Griffen, 1993). Eventually, the industry responded by developing a program to explain in simple, straightforward terms how BST works, how it is produced, and its role in dairy management. By now, however the damage had been done.

In 1985, the US Food and Drug Administration (USFDA) decided that milk and meat from BST-supplemented animals was safe for human consumption and products from test herds were allowed to enter the food supply. The safety of BST was reconfirmed by a USFDA Expert Advisory Committee in early 1993 and in November, 1993, USFDA approved BST for commercial use. However, in

May, 1993, USFDA held public hearings on whether milk and meat from cows receiving BST should be labelled as coming from BST-treated cows. Consumer advocates contended that the consuming public has a "right-to-know how their food is produced." The food industry contended that following BST through the distribution chain would be impossible and that if the food labels would have to be excessively complex if they were going to be meaningful. The industry felt that the correct approach was to evaluate the safety of the components of a biotechnology-derived food and then evaluate the safety of the entire food (Brooks, 1993).

Following approval by USFDA in November, 1993, Jeremy Rifkin the leading critic of biotechnology in the US announced demonstrations, boycotts, and campaigns to press for legislated bans on milk produced by BST-treated cows. Already, several large dairies and supermarket chains have announced their refusal to use it. According to Jane Brody (Herald-Tribune, November 19, 1993), 20-50% of consumers who have participated in various surveys have reservations about milk from BST-treated cows with those who know the least about it expressing the greatest concern. As Busch (1991) pointed out, the public is probably concerned about BST for several reasons: BST is not a vitamin like Vitamin D that is added to milk to improve the nutritional quality of the food, it won't really lower the price of milk like its supporters claim because milk prices in most countries are controlled by the government, and no one is really sure about the effects of BST use. Many people see BST as an attempt to increase the profits of the large pharmacuetical companies that produce the hormone and the large corporate farms that can afford to use it at the expense of the small farmers and consuming public.

THE SLOW-RIPENING TOMATO: HOW ONE COMPANY EXPLAINS BIOTECHNOLOGY

In direct contrast to the problems experienced by the companies that wish to use BST is the approach being taken by Calgene, Inc. in the marketing of their new Flavr Savr™ tomato (Newsome, 1993). Normally, tomatoes are harvested before they are ripe so that they will be hard enough to resist bruising during shipment. After shipment, they are ripened using doses of ethylene (a chemical normally produced by the plant to start the ripening process). This turns the tomatoes a red color, but leaves them with little or no flavor.

The new tomato has been genetically engineered so that it contains a copy of the gene that causes normal ethylene production in the tomato inserted into the tomato chromosomes in the "antisense" direction. This has the effect of slowing ripening so that the tomato can be left on the vine to ripen and, according to the company, "still get to market with the taste the way nature intended." For this product, Calgene has developed a distribution system that "handles the tomatoes very gently" so that they will not bruise in the distribution chain. The tomatoes will be marketed as "MacGregor" brand tomatoes (and not as another commodity tomato), and will be displayed in single layers on special carts in the supermarket. Labelling and information about the way in which they were produced will be provided. Rather than trying to hide the fact that this tomato is different, the company is emphasizing the differences and is providing as much information as possible so that it will not appear to be a type of "Sci-Fi" food. This is particularly important since Calgene is marketing this as a premium tomato with a target market of upper middle class, highly educated people. USFDA must approve the genetic engineering process before the tomato can be marketed.

THE PROPER INDUSTRY RESPONSE TO FEARS OF BIOTECHNOLOGY

People are always fearful of the unknown. If they don't understand something or know very little about it, they will always fear it and seek ways to control it. Biotechnology is one of these unknown or at best poorly understood ideas. The public needs to be made aware that this is a tool for helping to change biological materials presumably for the better, and not a technique for producing things more suitable for Star Trek than life in the late 20th Century.

Griffen (1993) listed the following items as necessary for communications between the biotechnology industry and the public:

1. Improve evaluation of social/ consumer needs and perceptions.
2. Promote public awareness and thus reduce fear of products.
3. Ensure development of open communications and flow of information.
4. Be more open and direct with people who help shape public opinion.
5. Ensure that messages are communicated in simple, easily understood language.
6. Accept that emotional arguments will not be overcome by scientific fact.

"Scientific validity counts for little when the public believes that there is something to be worried about".

It is necessary for the biotechnology industry, the companies that wish to use the products of biotechnology, and educational institutions where basic science is taught to educate the public so that they understand it. If they don't, biotechnology will be stopped dead in its tracks. This has already happened in Chicago, Illinois in the US (Kiernan, 1993). That city passed a law that became effective on October 3, 1993 in which restaurants and grocery stores must display a sign saying: "This food product has been genetically engineered" if they wish to sell items that have been modified through such processes as recombinant DNA and cell fusion. Establishments that fail to do so face fines of up to US$500. Jeremy Rifkin was quoted as saying (Kiernan, 1993) "Consumers do not want genetically engineered foods. Labelling means that consumers will bypass those foods, by and large." The local politician who sponsored the law said that his constituents have complained that there is no way to tell genetically-engineered produce from their "natural" counterparts. This of course, is the whole point of biotechnology, but the public obviously needs to understand that there is nothing inherently harmful in the technology. If the effort is not made, biotechnology will remain in the academic laboratory and will never be used commercially.

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