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Genetic Engineering of Crop Plants

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Objectives This unit is designed to acquaint students with the concept of genetic engineering and the biological and ethical implications involved. It will also help students understand the interplay between science, government, and the citizen, and the ethical problems involved in trying to feed the entire world population.

Goals The students will learn what genetic engineering is, how it is accomplished, and the biological problems involved. The students will also learn why there is such an ethical protest against genetic engineering and the resulting political and social consequences.

Unit Plan

Introduction

For as long as man has been cultivating crops and raising animals, there have been modifications of the genomes of these plants and animals. Just think of the large number of breeds of horses and dogs, and the many varieties of corn and tomatoes. Now we have the ability to modify the genome very precisely, one gene at a time. This new technique is called genetic engineering (GE), and has become a rather common technique in those laboratories conducting such research. It has made possible precise changes in varieties of plants, changes that have enabled man to increase both yields and the quality of these crops (Abelson and Hines, 1999).

However, there has developed a rather large and vocal opposition to the use of genetically modified organisms (GMOs). This opposition has attempted to stop the use of GMOs entirely, claiming health concerns such as toxic and allergic reactions, despite the assurances of the United States government Department of Commerce (Palmer, 1999), the National Academy of Science (Yoon and Peterson, 2000) and the United States Food and Drug Administration that there is no danger (Maryanski, 1995; Sudduth, 2000).

There are also claims that Monsanto and other companies involved are trying to “lock up” control of seed production and thus dominate the world. (Lappe and Bailey, 1997; Cummins, 1999; Bereano, 1995). Thus the arguments involved in the issue of GMOs safety might be characterized as both political and biological (Verzola, 1999; Rifkin, 2000; Genetic ID, Inc, 1999a).

Unfortunately there are a large number of articles that seem to be only alarmist in tone and content. Some of these are very well written, but many are not, and the overall effect is to alarm and confuse the reader, making it very difficult to sort out what is fact, opinion or fiction. (Fagan, 1998; Leahy, 2000; Pure Food Campaign, 1998; Rifkin, 1998). There has even been at least one news article written for children that seems to stress the potential harmful effects of GMOs (LeTourneau, 2000).

Biological Aspects

There seem to be at least four major objectives being pursued at this time in crop plant genetic engineering research. These are:

1. To improve biological protection of crops against insects, weeds and fungi by inserting genes for the natural production of an insecticide (Feder, 1996) or for resistance to fungi or an herbicide (Hinchee et al, 1988).

2. To elevate levels of important nutrients (e.g. methionine levels in soybeans - Beardsley, 1996) so as to make crops more nutritious.

3. To obtain better control of ripening and post-harvest storage life to assure that produce are in peak condition when taken to market (Maryanski, 1995).
4. To specifically modify genomes to produce a specific product (e.g. a caffeine-less coffee bean, edible vaccines in potatoes - Pollack, 2000).

The Process

Genetic engineering is the insertion of a segment of DNA containing one or more genes from one organism into a chromosome of another organism. This process, when successful, allows the expression of the added gene in the host organism. The process involves using either a virus or bacterium nucleic acid as a vector of insertion, or else doing the job with a micropipette or by bio-ballistic DNA delivery with a “gene gun” (Nicholl, 1994; Ho, 1996). To be sure that the gene you are trying to insert is actually present, the added segment of DNA usually includes a “marker gene” which is most often a gene for antibiotic resistance. The organism is then grown in a culture containing the antibiotic. Only those individuals with the added segment of DNA will survive, since they are the only organisms that are resistant to the antibiotic. At least this is how desired genes are usually identified, with a marker for antibiotic resistance. So far, there have been about 50 different food crop approvals for genetically engineered varieties (U.S.FDA, 2000).

Once the desired genes are inserted into the selected organism, the new genetically engineered organism is reproduced to obtain a generation of individuals that possess the desired trait. These individuals in turn are raised and utilized with the desired gene actively functioning. Some examples are the S-adenosylmethionine hydrolase gene from a bacterium which was added to cantaloupe to control ripening, the Phosphinothricin acetyltransferase gene from another bacterium which confers Glufosinate (Roundup©- an herbicide) tolerance, and the potato that is insect resistant with the cryIIIA gene from Bacillus thuringiensis (Bt) sp. tenebrionis (another bacterium) (U.S.FDA, 2000).

There are many other GMOs that have been produced and are being used for crop production at this time. There are 50 examples of genetic engineering reported by the U.S.FDA (2000). These GMOs confer resistance to pesticides, more uniform ripening, resistance to insects and viruses and improved protein content of several food crops. So why are there so many protests to genetic engineering?

The Problems

Any time the position of a gene is changed, there may be a change in the production of proteins. This may lead to unexpected results. The new protein produced may be intentional, as in the case of the production of protein by the Bt gene described below, or unintentional, as in the attempt to increase methionine levels in soybeans, the second case described below.

The Bt gene is a gene found in a bacterium and codes for the production of a protein (Bt) that is a natural insecticide. This gene has recently been engineered into corn, tomatoes, cotton and potatoes (U.S.FDA, 2000). This would mean that we could have plants with a built-in insecticide, and this insecticide would greatly reduce the use of harmful chemical insecticides in the environment. But very quickly three very disturbing problems seem to be arising. One, will insects develop a tolerance for this protein? This seems to have occurred in some trials of engineered cotton in Texas. Two, will the Bt gene “escape” into the wild, weedy relatives living in the area? If this happens, will they have an advantage over native plants in that the weeds will be more resistant to insects? (Feder, 1996; Beardsley, 1996a). And three, will the Bt toxin affect humans? It seems as if we are not entirely sure of what we are attempting.

In an experimental attempt to boost the methionine level in soybeans, a gene from Brazil nuts was introduced into a soybean variety intended for use as animal feed. But the introduction of a new gene may lead to the production of a new protein (Fig.1). In this case the new protein caused a “life-threatening allergic reaction in people”(Beardsley, 1996). The company quickly stopped the project (Beardsley, 1996; Feder, 1996; Leary, 1996). Here again we see an unexpected result from an attempt at genetic engineering.

This “life-threatening allergic reaction” was a determination made in the laboratory using blood serum from nine patients who were allergic to Brazil nuts (Leahy, 1996). All nine reacted to extracts of the Brazil nut. Eight of nine reacted to the genetically engineered soybean extract, but none reacted to the extract from regular, plain soybeans. Skin prick tests on three volunteers showed the same results. This was part of the normal pre-release process that genetic engineering companies are required to perform on their own by the FDA (Sudduth, 2000). This example of a potentially serious result is often quoted by opponents to genetic engineering, even now, five years after the fact. And it is frequently implied that people were put at serious risk, even though all of the allergic reaction procedures were done in the laboratory on blood serum and no one became ill.

Insertion of a desired gene requires not only a vector for insertion, usually a viral gene, but also a marker gene for antibiotic resistance. One other problem is that each gene inserted into another organism needs an activator gene. The host organism is very unlikely to furnish this activator, so one is usually provided with the inserted gene. Virus activator genes have evolved to overcome host cell indifference to an added gene. These virus genes are very powerful activators, and are normally what is used to activate an inserted gene (Steinbrecher, 1999). There are also some bacterial activators used. We do not know the long-term effects of using these microbial genes in genetic engineering. If they are passed to other organisms there may be problems that we cannot imagine at the present time.

Figure 1.

A. Normal Gene Position

Repressor Gene Activator Gene Structural Gene

B. With Inserted Gene from Transgenic organism

Repressor Gene Activator Gene Inserted Genes Structural Gene

Blockage No expression or changed protein expressed

The position of the inserted genes may have an effect on the organism. If the insertion is in the middle of another gene, it will effectively block the expression of that gene. Using a gene gun or microbial transfer, we have no knowledge of exactly where genes may be inserted. We are basically “shooting in the dark” and hoping that we place a gene into the genetic makeup of a host cell in a location where it can be effectively expressed. This insertion may make a host structural gene inoperative or it may destroy an activator gene (Figure 1). Either way, it may change the genetic expression of the host in an unexpected fashion.

Finally, we can see that the insertion of one transgenic gene actually involves the insertion of at least four separate genes, i.e:

1. The insertion vector gene (usually a virus)
2. The marker gene (usually for antibiotic resistance)
3. The activator gene (usually a virus)
4. The transgenic structural gene

In addition the position of the inserted set of genes has a great effect on gene expression and protein production. It becomes apparent that this process is far more complicated and imprecise than has been stated by proponents (Maryanski, 1995).

The Justification

The use of genetic engineering as a tool to improve crop plants for human use is an idea that should be irreproachable (Farnham et al, 1999; DellaPenna, 1999, Mazur, et al, 1999). The four major areas of research indicated above are certainly all worthy areas of endeavor. But perhaps the ultimate justification for genetic engineering is the specter of an entire world in famine. There are now six billion humans on this planet. Within the next fifty years we will be very close to nine billion people. If we do not discover and quickly use some effective form of population control, we will have to produce much more food than we are producing at the present time (Prakash, 1999). By the year 2025, we will need to raise cereal grain production eighty-five percent over the 1990 level if we are to keep pace with population growth (Serageldin, 1999).

Genetic engineering is one way by which we may be able to boost the production of food to needed levels. Food crops with built-in insecticides, such as the Bt toxin, should be easier, safer and cheaper to grow, and produce higher yields. Those crops that are tailored nutritionally should be able to eliminate some serious chronic deficiencies in diets in some parts of the world. Fruits and vegetables that ripen when needed should make it possible to get more produce to market at the optimum time, minimizing waste. Plants that are genetically engineered to produce some specific product may entirely change the economics of medicines and make some drugs much more available than at the present. GMOs may also be able to provide some effective method of birth control (Pollack, 2000; Farnham et al, 1999).

Political Aspects

Despite all of the promise shown above, we are not making as much progress as we might be. Why? Because there has developed an enormous protest to the entire idea of genetic engineering. This protest does not seem to be abating, and has spread to many countries around the world. Those people protesting GMOs are very vocal and very well organized (see AmeriScan, 2000; Anon., 2000, Arnett, 2000; Genetic ID, 1999; Mothers for Natural Law, 1999, 1999a, 1999b, 2000; Natural Law, 2000; and others). Some of the protests seem frivolous, some seem legitimate and all of the protesters seem to show genuine concern. What are these people saying?

Nature of the Protest

Of all the protest materials which I have read, there seem to be several specific categories into which most of the protests to genetic engineering fall:

1. That genetic engineering will produce a protein that will subtly cause allergic reactions in people.
2. That the Bt insecticide produced in plant tissue will poison people eating the plant.
3. That crops, especially fruits, produced using genetic engineering will be tasteless or will taste bad.
4. That GMOs will have an adverse effect on wild plants and animals.
5. That genetically engineered crops will have an adverse effect on natural ecosystems.
6. That genetic engineering is unnatural and will produce GMOs that could never come from nature.
7. That the viral and bacterial vector and activator genes used may be recombined in the wild and form some deadly new pathogens.
8. That GMOs are an attempt by large corporations to obtain a monopoly on seed production and thus dominate the world.
9. That we don’t need genetic engineering and more food anyway, we simply need to develop more efficient means of food distribution.
10. That genetic engineering is evil.

Some of these objections are valid, others seem not to be. Before we examine these objections in more detail, we should say something about how these protests are being carried out.

Methods of Protest

This protest seems to be the first that has utilized mankind's new-found attachment - the internet. There are a large number of web sites devoted to the protest of genetic engineering (see AmeriScan, 2000; Anon., 2000, Arnett, 2000; Genetic ID, 1999; Mothers for Natural Law, 1999, 1999a, 1999b, 2000; Natural Law, 2000; and others). The use of the internet has made it possible for people to bombard their congressman/woman with complaints, and to do so repeatedly since it is easy to use a new name each time, and hard to trace communications using many e-mail addresses.

There are a large number of articles on genetic engineering found on the internet, many sound in their science and point of view. But there are also many articles that show little understanding of the biology involved in genetic engineering. See for example the two letters to the editor of the Washington Post (Dushay, 2000; Young, 2000). These letters are a reply to an article discussing genetic engineering of characteristics such as "hard work, courage, and creative imagination" . The author of the article (Michael Kinsley) seemingly did not understand the complex interrelationship between heredity and the environment.

Another tactic used by opponents of genetic engineering is that of overstating the evidence. For example, researchers in a laboratory at Cornell University fed Monarch butterfly caterpillars Bt toxin by dusting pollen from Bt corn on the leaves of milkweed, the sole food of Monarch caterpillars. Approximately 50% of the caterpillars died within four days and those left living did not appear to be healthy. These results were published in many articles (Center for Science and Media, 1999; Leahy, 2000; LeTourneau, 2000) and most of these articles seemed to imply that the natural populations of monarchs were in danger. In only one article (Center for Science and Media, 1999) was it made clear that this study was done in the laboratory and that the situation has not yet been examined in the wild. The results of this experiment were definitely overstated and generalized. We must now explore the question of the validity of protests against genetic engineering.

Validity of the Protest

One of the most repeated criticisms of genetic engineering is that it is creating unnatural organisms that could not possibly occur in nature and that these organisms are only produced in the laboratory and could never be produced in nature (Genetic ID, 1999). However, there are GMOs produced naturally, as well as in the laboratory (Hilts, 1996).

There have been several incidents in the past several years of people becoming sick, and some actually dying, from hemorrhagic colitis. This disease is a severe form of diarrhea and is caused by the Escherichia coli bacterium, strain O 157: H7. But E. coli is common and normally present in large numbers in the intestinal tract of mammals. What caused this strain to become so virulent?

There is another bacterium named Shigella dysenteriae . This bacterium produces Shiga toxin which causes diarrhea. The gene for Shiga toxin has jumped from Shigella to E. coli. When present in the much more common E. coli the Shiga toxin gene causes the production of the Shiga toxin in large quantities. If undercooked meat, especially ground hamburg with its large internal surface area, is eaten the E.coli in the hamburg ends up in the intestine. If it is carrying the gene for Shiga toxin, hemorrhagic colitis will result (Hilts, 1996).

This seems to be a case of natural genetic engineering. But the consequences for man have been severe.

Many people have been stricken with hemorrhagic colitis and a few have died. In the Jack-In-The-Box restaurant incident of 1993 four children died and many people were stricken. In July, 1996 the same strain of E. coli caused extensive food poisoning in Japan, with at least four deaths reported (Anon., 1996b). A later report sets the death toll at 100 and the number stricken at 8700. It was reported that there were 100 new cases per day (Anon, 1996c).

From the Shiga toxin results, we can see that the distinction between man-made GMOs and naturally occurring GMOs is rather meaningless. There is no support for the idea that man-made GMOs are inherently “bad” and natural GMOs are somehow “good” because they are natural.

At this point in time, we are facing a world population of six billion people. By 2050 estimates are that the population will be almost nine billion people (Prakash, 1999). GMO opponents say that increased and more efficient food transportation will solve the hunger problem. Most reputable scientists say that we must produce more food (Miller, 1990). To improve general levels of health, we must also increase plant phytonutrients, particularly micronutrients. These include organic phytonutrients such as vitamins and specific amino acids and inorganic phytonutrients such as calcium, iron and other minerals. These increases are possible through the manipulation of the secondary metabolisms of plants by the use of genetic engineering (Farnham et al, 1999; DellaPenna, 1999, Mazur, et al, 1999).

We must, by some method, raise food production soon if we are to feed everyone. Even today there are millions of people starving in our world. It is mainly but not entirely a question of distribution. At the present time, while our world population increases, our natural resources decline even further. We have less arable land to farm each year. Many acres per year are lost to erosion, urban and suburban sprawl, and shopping malls. And our soils become more polluted every year. By the year 2025, we will need to raise cereal grain production eighty-five percent over the 1990 level if we are to keep pace with population growth (Serageldin, 1999). The use of GMOs may be the solution to many of our food production problems (Prakash, 1999).

Today seventy four percent of the genetically engineered acreage is planted in the U.S. and ten percent in Canada. Argentina plants fifteen percent. The rest of the world plants only one percent. The five major GMO crops are soybean, maize (corn), cotton, rapeseed (canola oil) and potato (Serageldin, 1999). Both genetic engineering products and processes are patented. Many of the genes used in genetic engineering come from plants and animals found in third world countries. There is growing concern among these countries that they will have furnished much of the raw genetic materials, but will not be able to afford the products produced. (Moffat, 1999a; Overseas Devel. Inst., 1999).

Perhaps unfortunately, many large global conglomerates are rapidly buying up biotech and seed companies, as well as agribusinesses and agrochemical companies. The control of the agricultural seed and pesticide industry is rapidly falling into the hands of these large corporations. (Rifkin, 1998). This concentration of control is significant, with only ten companies controlling 37% of the global seed market, and only ten companies controlling 81% of the global agrochemical market. (Rifkin, 1998).

It is easier to genetically change plants and microbial organisms than it is to alter the genetic composition of mammals (Somerville and Somerville, 1999). Many genes for genetic engineering have come from contributors of blood samples and seeds from third world countries. These genes have then been patented and commercialized so that third world farmers cannot afford to use the genetic products produced. (Shiva, 1997). The discovery and use of these genomes is called “bioprospecting” (or “biopiracy” by its detractors) (Snell, 1995).

This control and patenting of genomes makes it almost impossible to make knowledge freely available to third world farmers and research institutions. But normally third world (Southern) countries are not competing in targeted Northern markets. This makes it possible for information to be shared without violating patents. Monsanto and other companies are currently sharing information with third world countries (Serageldin, 1999). Thus there may be some hope of increasing third world crop quantity and quality without depriving Monsanto, Dupont, Novartis, Upjohn, Eli Lilly, Rohm and Haas, Dow Chemical, Amgen, Organogenesis, Genzyme, Calgene, Mycogen, Myriad, Bayer, Rhone-Polenc and others of their share of the genetic engineering market (Rifkin, 2000, Pure Food Campaign, 1999).

But even with organisms engineered from local species in the U.S. there are ethical questions raised. A plant has recently been genetically engineered to take up mercury from the environment (anon., 1996a). The plant will absorb very large quantities of mercury from the soil as it grows. The plant may then be harvested and the mercury is removed from the environment along with the plant. Plants have also been engineered to pick up excess amounts of copper, cadmium and aluminum in the soil (Moffat, 1999). But this has only been accomplished in the laboratory and we do not know the effects of releasing these altered genomes into the environment. The effect might be one entirely unexpected. For example, what if the plant also takes up abnormally large quantities of an essential mineral? What would happen to the soil? Or what would happen if the gene for mercury accumulation “jumped” (horizontally moved) to an important crop plant? And how and where do you dispose of the plant material loaded with mercury? It is these kinds of uncertainty that seems to be driving the protest movement.

In another carefully controlled experiment, Rapeseed plants were genetically engineered with a gene for resistance to the herbicide Roundup©. These plants were then allowed to grow with a native related plant, a weed called Wild Mustard. The result was that the genetic package making Rapeseed plants tolerant to the herbicide Roundup© was horizontally moved to this related wild species, Wild Mustard, and the weed ended up with the genes for resistance to the herbicide. (Beardsley, 1996a). Horizontal movement is the term usually employed when talking about the transfer of genetic material from one species to another in the wild (the terms “escaped genes” and genes that “jumped” are also often used). In this case the experiment was closely controlled, all the plants were destroyed and there was no harm done (Beardsley, 1996a). However, this experiment does show how easily genes can escape from genetically engineered crops into the surrounding natural environment. Much more serious problems may develop if some of the viral and bacterial genes are horizontally moved in the soil to other microorganisms. There is the real potential for the development of some very pathogenic microorganisms. (Ho and Tappeser, 1997; Beardsley, 1996a). And this is another large concern of protesters.

The Bt gene is a gene naturally found in a bacterium and codes for the production of a protein that is a natural insecticide. This gene has recently been engineered into corn, cotton, tomatoes, rapeseed and potatoes (U.S.FDA, 2000). There are great fears that this natural insecticide will somehow poison humans, and that crop pests will become resistant to it. There is some indication that this developing resistance may already have started (Feder, 1996). But one aspect that few people seem to be taking into account is the action of this insecticide.

There are two excellent articles on the biology of the Bt toxin and the possible horizontal movement of the Bt gene in nature (Tappeser, 1997; Tappeser et al, 1998). The Bt gene is naturally present in the bacterium Bacillus thuringiensis and codes for the production of a protein. This protein is found as a crystal in the bacterial spores in parasporal inclusion bodies. Normally the larva of an insect will take in the bacterial spores when it is ingesting the leaf tissue of a host plant. When the spores reach the intestine of the insect larva, the parasporal inclusion bodies are released.

The alkaline pH of the insect intestine causes the released Bt crystalline protein to become soluble. This protoxin is split into two smaller toxin proteins by an insect protease enzyme present in the gut. These smaller proteins penetrate the peritrophic membrane of the intestine and reach specific receptors on the cells of the intestinal wall. This results in the destruction of ion gradients and in the formation of pores which allow the vegetative Bt cells which have germinated from the spores to pass into the haemolymph, causing an intoxication of the insect larva. The larva becomes anesthetized and dies from exposure, dehydration and starvation. (Tappeser, 1997).

With genetic engineering the Bt gene has been added into the cells of some crop plants. When an insect larva chews on a leaf of one of these crops, the gene has already produced the Bt protein in the smaller, cleaved toxin form, and this has the same toxic effects on the intestines of the larva. The larva is effectively killed. In this case, there seems to be no need to consider the protoxin. The toxins are present in the cells and act directly on the insect. (Tappeser, 1997).

It is hard to imagine these toxins having an effect on the human system. First, much of our food is cooked, which would denature these proteins. Second, the intensely acidic pH and protease enzymes of our stomachs would also denature and hydrolyze these proteins. It seems almost impossible that these toxic proteins would have any effect at all on humans. And to date there have been no reports of such effects.

As a result of genetic engineering there may be changes in the nature or amounts of the proteins produced in the transgenic plant or in the amounts or kinds of toxicants present. These changes are called pleiotropic effects. Many of the effects may be toxic or allergenic. The U.S FDA’s own internal memoranda show that within the FDA many scientists have had misgivings about allowing GMOs to be released for use without thorough testing for toxicity and allergenicity (Mothers for Natural Law, 1999a). These internal memoranda became public documents as the result of a lawsuit brought against the FDA to try to force the government to use some system of independent testing of GMOs before they are released (Coale, 2000).

Who is responsible for guaranteeing the safety of GMOs? The Bt gene and toxin seem to be guaranteed by no one. It is not a food additive so the FDA does not test it. It is an insecticide and therefore the FDA is prohibited from dealing with it. The Environmental Protection Agency (EPA) deals with pesticides. Except Bt is in a food, so the EPA tests only the isolated toxin in the laboratory, not as it is in the foods (Lovins, 1999). The United States Department of Agriculture (USDA) only concerns itself with additives to meat, fish and poultry. Bt toxin is there, an orphaned toxin without a regulating agency (Pollan, 1998). This situation is so frustrating to those concerned that there is a lawsuit against the FDA for failing to test GMOs (Coale, 2000).

One of the plant crops most used by the food industry in North America at the present time is the soybean. It is a source of proteins, oils and emulsifiers and is a basic ingredient in a very large number of processed foods. The soybean has been genetically engineered to change the composition of the oils produced, and to be tolerant of glyphosate (Roundup© herbicide) by increasing the concentration of the enzyme that controls aromatic amino acid biosynthesis. This biosynthetic change has greatly increased the isoflavonoids (phytoestrogens) present in soybean tissue. Using Roundup© on soybeans seems to further increase the levels of phytoestrogens. These act like regular mammalian estrogen hormones and effect sexual differentiation, blood clotting, calcium metabolism, cancerous tissue changes and immune functions. High doses of phytoestrogens, particularly in infants (from infant soy formulas), may cause serious health problems (Lappe and Bailey, 1997).

There are also a number of legal issues involved with genetic engineering. Who owns a gene? If you genetically engineer a gene into a host plant, you can patent the resulting transgenic plant. So genes are patentable and in a sense if you patent a gene it is yours. But if you sell your patented genes in plant seeds, what happens to them? A farmer will plant your seeds and raise your patented plants. Who owns the seeds from these plants? Many farmers, most in third world countries, save seeds from their crops each year to plant the next year. But these saved seeds are now patented! This forces the farmer to buy new seeds each year, and there is often an accompanying enforceable contract that says the farmer will buy pesticides only from the seed vendor! The legal issues over ownership of patented genes and seeds is still in flux. But it seems that the small farmer, who can least afford it, is stuck in a very expensive system (Bereano, 1995, 1995a).

Other legal issues concern the rights of third world countries to benefit from genetic engineering (Overseas Devel. Inst., 1999). If governments set too stringent standards for releasing GMOs into the market, the third world countries and the smaller producers will be economically shut out of this market (Huttner, 1999). And it is these smaller producers and countries who might benefit most from genetic engineering technology.

How is the rest of the world reacting to genetic engineering? For the most part genetic engineering of food crops is not being accepted. In Europe there is an active and vigorous opposition to GMOs (Gaskell et al, 1999; Daley, 2000). This opposition has spread to most of the food-importing countries of the world (Genetic ID, 1999, 1999a). The European Union has developed guidelines for GMOs (European Union, 1997) and the U.K. has revised and expanded guidelines for experimenting with GMOs (Health and Safety Exec. - U.K., 1998). There are serious environmental concerns in the U.K. which are now being addressed (NERC, 1998). The argument between the United States and the European Union over labeling of GMOs has not been resolved (Lyddon, 1999, 1999a). And yet, even with all of this global opposition to genetically engineered food crops, there has been hardly a decline in production of GMOs in the United States (Barboza, 2000).

There are a number of ethical issues involved in the genetic engineering controversy. Who has the right to the products of genetic engineering? Do large, transnational companies have the right to prohibit third world countries from using indigenous plants because their genes have been patented? (Ho, 1996). To what extent are we upsetting ecosystem balance using genes that may be moving horizontally though the ecosystem? (Fong, 2000; Rifkin, 1998). The danger of genetic engineering to the biosphere has been compared to the use of nuclear weapons and atomic energy. Horizontal movement may be the next Chernobyl! (Mann, 1999). We simply do not know the consequences of this large uncontrolled genetic experiment we have started. In the near future we may suffer massive genetic pollution and loss of genetic diversity, but we are presently taking no steps to prevent the disaster. (Rifkin, 1998).

We as a society have experienced events in our recent past that are at least perhaps partly comparable to genetic engineering - atomic energy and DDT. Each of these new technologies initially was promoted enthusiastically as a cure-all for mankind but was later found to be encumbered with hidden risks. Will genetic engineering have a similar history? (Epstein, 2000). We are proceeding rapidly with this new technology, but we are not being at all cautious about the possible long-term effects of genetic engineering. This may be in part because of the continued movement of high-level officials from government to industry to government (Epstein, 2000).

There is a rather large number of upper-level government officials who have taken executive positions with Monsanto, including an ex-cabinet secretary (Mickey Kantor, Secretary of Commerce) and an assistant to the President (Marcia Hale). And a number of Monsanto executives have taken upper-level management positions in the U.S. government. One Genentech executive (David Beier) has become an advisor to Vice-President

Gore’s presidential campaign. The advantage seems to be entirely on the side of the large transnational companies. This revolving-door employment must have an effect on the policies of the federal government on genetic engineering (Epstein, 2000). Most opponents of genetic engineering say that the U.S. government is trying to force genetic engineering onto the rest of the world. (AmeriScan, 2000).

The three basic ethical issues involved in genetic engineering seem to be: 1) Does anyone have the right to patent genes? How can we assure everyone of equal access to genetic materials and the resulting products? Cost must be universally low and reasonable. Who will monitor this? 2) Genetic materials and experiments must be kept under tight controls and carefully tested . The U.S. government and agrochemical companies seem to be pursuing a policy that greatly benefits the genetic engineering industry and ignores legitimate concerns about safety. There seems to be no regulatory agency that is responsible for GMO safety. 3) No one seems to be addressing the issue of long-term environmental risk. What might happen to ecosystems if pathogenic genes undergo horizontal transfer? Might we be subjected to an eco-disaster? Why have we neglected testing for long-term effects?

Conclusions

Some of the opposition to GMOs seems almost irrational(Fong, 2000). Two Mothers for Natural Law web articles (1999 and 2000) assume that there is something to be avoided in genetically engineered foods. They furnish a list of food products to avoid, and a source for testing DNA of food products for genetic engineering. There is no discussion or justification for what they are saying. The assumption seems to be that if it is a GMO it is bad. There may well be some problems with GMOs, such as allergic reactions, changed flavors and horizontal movement of genes, but these need to be investigated in a rational manner, not with blanket condemnations and ignorance.

It is probably a positive thing that protesters have called attention to the phenomenon of genetic engineering and have insisted that the government be more active in the testing and licensing of these products. At the same time, there seems to be much misinformation and some hysteria about the subject of genetic engineering. There have been all kinds of dire predictions about GMOs. But genetic engineering has been singularly free of tragic consequences to date. The one exception seems to be the production of tryptophan by a Japanese company. Eleven people died from consuming tryptophan that was improperly genetically engineered and purified. However, we may conclude that the general short-term effects of genetic engineering on humanity is positive.

However, there seems to be no research being done on the long-term effects of genetic engineering. There are several basic questions unanswered:

1. Will people over time develop allergic reactions to the transgenic proteins produced from genetic engineering?
2. Will the horizontal movement of genetic materials have a negative impact on ecosystems?
3. Will some virulent new pathogen develop from the transfer and transformation of microbial DNA made available by genetic engineering?
4. Will humans be able to make the correct ethical choices so that all of humanity may share in the potential benefits of genetic engineering?

Finally, from all I have read, I have concluded that genetic engineering can be of great benefit to humanity. But at the same time, I deplore the haste with which the biotechnology industry has pursued the production of GMOs and profit. The lack of research on possible long-term effects of genetic engineering is appalling.

Notes to Teachers on the Laboratory Exercises:

There are a number of points that need to be made to the teacher:

1. Roundup© is an herbicide and a poison. It has been implicated in non-Hodgkins lymphoma. It is easy and safe to apply, but you may want to do it yourself. A light spray on the leaves is all that is needed. Do it when there is no breeze!

2. Organic foods, obtainable in a health food store, are not genetically engineered. This is your source of soybean seeds, corn meal and tomatoes. The genetically engineered seeds may be purchased at an agricultural seed company, such as Hartz or Asgrow or Agway. Genetically engineered corn meal and tomatoes come from

the supermarket. 3. I do not know if you will have a suitable oven available. I have one I can use in the teacher's room. Maybe you can use one in the cafeteria kitchen?

4. If you simply give the students two samples, and do not tell them which is which, you may obtain more unbiased results.

Roundup© Ready Soybeans

There is a very effective herbicide on the market called Roundup©. This poison is manufactured by Monsanto, who also sells a genetically engineered soybean called Roundup© Ready. This soybean has been engineered with a gene from the bacterium Agrobacterium that makes the soybean plant tolerant to the herbicide Roundup©. Thus one can plant these soybeans, wait until they are growing and six inches tall, and then spray the entire field with Roundup©. All of the weeds will die, leaving only the Roundup© Ready soybeans. We can demonstrate this rather simple example of genetic engineering in the laboratory.

The procedure is as follows:

1. Work as teams of two. Each team needs to obtain from the teacher the following supplies and equipment.

a. Two styrofoam or paper cups filled with soil.
b. Six soybean seed, three of each type - Roundup© Ready and plain.
c. Two popsicle sticks to use as markers and probes.

2. Label the cups on the side - use RR and PL. Include your initials. Punch a hole in the bottom of each cup with a pencil (allows excess water to drain out).

3. Plant the soybean seeds about one inch deep in the soil. Place the three seeds of one type in one cup and the three seeds of the other type in the other cup.

4. Water the soil in both cups.

5. Place the cups in a window with plenty of sunlight. Water the cups every two or three days.

6. Keep a record of plant growth for each of the six plants.

7. When the plants are about 6 inches tall, spray each set of plants with Roundup©. Remember - THIS IS A POISON - it kills plants and has been found to cause cancer in laboratory mice. USE WITH EXTREME CAUTION (Your teacher may wish to do the spraying of the Roundup© herbicide!).

8. Continue to water the plants and observe what happens over the next two weeks. What was the effect of Roundup© on each type of soybean?

9. Write a laboratory report on your observations, explaining what happened and why.

Normal and Genetically Engineered Corn

There may be a noticeable difference between genetically engineered corn and plain corn. There might be a difference in taste. How could we discover if this is true? By making some simple corn dish such as corn bread. Most of the cornmeal available in supermarkets contains at least 50% genetically engineered corn. Corn meal purchased as "organically grown" and certified, contains no genetically engineered corn. The difference is quite easily shown in the laboratory. The procedure is as follows:

1. Work as teams of three. Each team needs to obtain from the teacher the following supplies and equipment.

    a. 1 Cup of regular corn meal
    b. 1 Cup of organic corn meal
    c. 1 Cup of sugar
    d. 11/2 Cups of biscuit mix.
    e. 2 aluminum cake tins

2. Make up two batches of corn bread mix, using the following proportions:

    a. 1 Cup corn meal - (regular for one, organic for the other)
    b. 1/2 Cup sugar
    c. 3/4 Cup biscuit mix
    d. 1 Cup water.

Mix all of the ingredients together in two cake tins and mark the tins by bending the rims.

3. Place the two tins in an oven and bake at 350°F for about twenty minutes, until a knife blade inserted in the mix comes out clean.

4. Taste each corn bread. Can you detect any difference in taste? Is there any way to determine if any taste difference can be attributed to genetic engineering?

5. Write a report on this laboratory. Include your impressions and the vote of the entire class. Why do you think you obtained the results that you did?

Storage Life of Normal and Genetically Engineered Tomatoes
One of the recently introduced genetically engineered products is tomatoes that have a longer shelf life. Students can compare very easily the shelf life of genetically engineered tomatoes and organic tomatoes. Simply buy some of each and see how long they last in the classroom on the window sill. The students might also wish to periodically taste them, to see if there is any difference in taste.

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