BIOTECHNOLOGY 101: WHAT YOU NEED TO KNOW IN A FEW MINUTES

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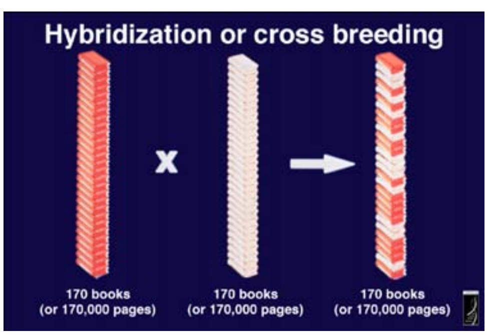
INTRODUCTION

Various reports and stories have been written about the new, what many call GM (genetically modified) or GE (genetically engineered) foods. The process by which these foods are created is referred to as biotechnology or recombinant DNA. All of these terms refer to the use of new ways to modify the genetic makeup of crops and animals. What is a GE food anyway? To answer this question and also to evaluate scientifically the risks and benefits of these products, it is important to have an understanding of how the genetic methods used to create these foods work. And how these methods are different from or the same as the genetic methods that have been used for thousands of years to change the foods we eat.

Let's take a look at alfalfa. The uniqueness of the different varieties of alfalfa, their identifiable growth habits and their disease tolerance, for example, leads to notable differences in varieties. That uniqueness is due in part to the genetic information, which determines whether the variety is downy mildew resistant, has a high protein level, a dense stand or a high relative feed value. That information, contained in the millions of individual cells of the alfalfa plant, is written in a chemical language, made up of chemical units, much like the letters that make up the text of this paper. That information is organized in paragraphs, which in genetic language are genes. The genes can be thought of as recipes, which dictate exactly how the organism grows, what it looks like and how it performs. If alphabetic letters were used to represent each chemical unit, 170 books, each of 1000 pages, would be needed to hold all of the information for a particular alfalfa variety.

CLASSICAL AND MARKER ASSISTED BREEDING



What if we wanted to create a new alfalfa variety? If we used classical breeding methods, we would cross pollen (male cells) of one variety with eggs (female cells) of another variety and then look through the resulting plants to find an alfalfa variety with the new traits we wanted. What happens with the genetic information in the cells when you do that? Are the two sets of books combined to give 340 books? No, genetic rules say you can only end up with 170 books, so 50% of the information from each parent is lost. The breeders can't control which information or pages of the books are kept, but

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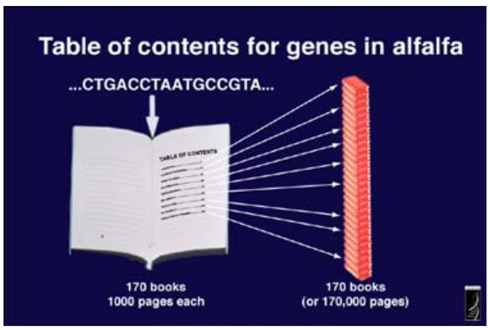
they can only observe the results and choose the plants that appear to have the characteristics that they want. This method was used to create most of the commercial alfalfa varieties available today.

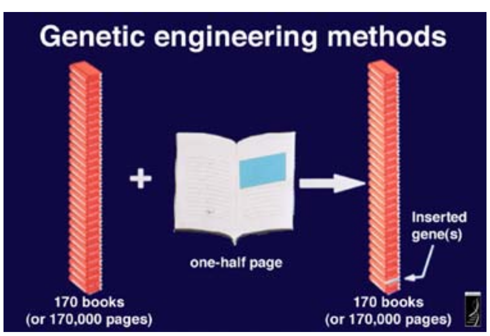
But alfalfa varieties have different characteristics and predicting precisely the traits that the new varieties will have after classical crosses is difficult. New methods, based on recently developed molecular information, are available to help breeders predict which plants from a cross have the characteristics they want – ones that they can't readily determine by just looking at the plants. This is called marker-assisted breeding and involves the breeder looking for specific chemical language, also called a marker, in the genetic information of the plant and making sure that the specific language is in the plants they choose. It is like looking for a specific sentence in a novel using the "Find" command in a word processing program. When breeders find that the desired chemical sequence is in a particular plant, they can be relatively sure that the trait they want will also be present in that plant. This is like knowing you are close to your home because you see a particular building that you know is near your home.



The identification of the specific markers that breeders use is made possible because of new information available through the science of genomics. What is genomics? One aspect of this science is reading the chemical language for all of the information in a particular organism, which is called the genome. Reading the genome allows scientists to develop a genetic table of contents for the organism, so it is possible to locate specific information in the genome. Although the entire alfalfa genome has not been read yet (efforts are underway), there is enough information that breeders have some markers to help them with their breeding efforts. This can speed up the development of new varieties by many years.

GENETIC ENGINEERING

Another way to use the new genetic tools is to move specific genes to change a plant's characteristics. In reading the entire genome it is possible to identify various genes and determine what characteristics of the plant a particular gene is responsible for. Once that information is known, it is possible to use chemical scissors to specifically cut out the gene equivalent to a half-page of information in the 170 book set. This process is similar to using a word processing program first to find a particular sentence and then to use the "cut" command to remove the sentence. Once removed, the gene can be reinserted back into the genome by chemical "pasting", again similar to pasting the removed text back into the same document or a new document. The tools and process of cutting and pasting the genetic information is referred to as recombinant DNA and the resulting organisms would be referred to as GE (genetically engineered), or as some prefer, GM.



But the gene is not what actually gives rise to the new characteristic. Genes code for proteins, which actually do most of the work in the cell. To ensure that the gene-encoded protein is made in the right tissue at the right time, genes have switches, or promoters, that tell the cell when and where to make the particular protein. Genes that are present in the genome have these switches, but sometimes they have been turned off or are turned on in the wrong parts of the plants. With genetic engineering we can attach different switches that result in the protein being made at the right time and place. For example, if a gene is introduced to protect against a disease of the root, that protein could be under a promoter that causes the protein to be made only in the root, not in the leaves or the seeds. In addition to the "on" switch, genes also have "off" switches, or terminators, that indicate where the information to make a certain protein ends.

Once the gene has been attached to appropriate on/off switches, how is the gene introduced into the alfalfa plant? There are two main methods scientists use. One uses a naturally occurring soil bacterium capable of moving part of the DNA from its genome into a plant cell. Once the DNA enters the cell it becomes a part of the plant cell's genome. Scientists learned how to substitute the gene they wanted to introduce for the bacteria's gene. In this way, when the bacteria inserts the DNA, the gene of choice is moved into the plant cell's genome. Another method to introduce genes involves physical force using what scientists call a "gene gun". This method uses tiny particles, about one-thirtieth the size of a cell, that are coated with the gene you wish to introduce. The particles are projected at high speeds into the cell where the genetic information comes off and incorporates itself into the genome of the plant cell. The plant cell then multiplies and is "coaxed" to reform an entire plant

COMPARING CLASSICAL BREEDING AND GENETIC ENGINEERING

Are classical breeding and genetic engineering the same or different? It depends on how you look at it. Both methods use naturally occurring cellular machinery to move genes around and both cause genetic changes that can be passed on from generation to generation; in other words they are heritable. So in that sense they are the same. But there are also differences. In the case of classical breeding the changes occur inside the cell, while with genetic engineering scientists make the changes in the laboratory. Also during the breeding process, keeping a particular gene is a random process; the breeder cannot specifically control which genes end up in a particular plant after a cross, although marker assisted breeding makes this easier. With genetic engineering, scientists specifically chose the genes they introduce into the plant.

Perhaps the most fundamental difference between the two methods is that gene exchange by breeding takes place most often between closely related plant species, although gene exchange can occur at low frequencies across species barriers. For example, rye (*Secale*) was crossed with wheat (*Triticale*) to create *Triticale,* a crop species grown for animal feed in certain parts of the U.S. In contrast to the situation with classical breeding, the gene source used with genetic engineering can be the same plant, another plant or even a different organism, like a bacteria or an animal. Why? The reason is that the same chemical language is used for the genetic information in all living things. And not only is the same chemical language used for the genes in all organisms, but humans and plants even share many of the same genes (~40-60%).

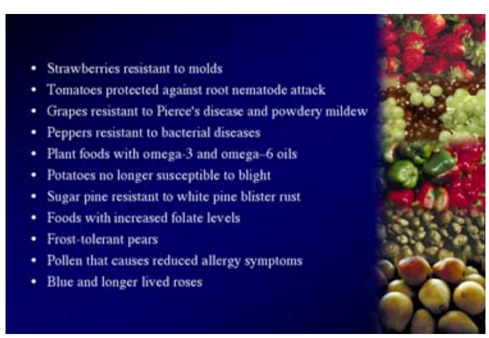
WHAT'S OUT THERE?

So how many different crops we grow and foods we eat are genetically modified? It depends on your definition. If you mean in how many crops have genetic changes occurred – even at the hands of humans - the answer would be all, including those grown under organic certification. Take for example corn whose ancient relative looked little like modern corn. Its seeds were small, in drastically reduced numbers and impossible to open with your teeth.

If you mean how many different plants that are commercially available have been changed by genetic engineering, the number would be very small. While many processed foods, except those labeled 100% organic, may contain a GE ingredient, they come from a small number of large acreage GE crops, like corn, soy, cotton and canola. In 2002, 75% of soybean acreage, 71% of cotton, 32% of corn and 54% of canola acreage was planted with varieties developed through genetic engineering. Because oil, *e.g.*, cottonseed, corn and canola, and meal, *e.g.*, corn, soy and cottonseed, from these crops is in many foods, the percentage of foods with one of these ingredients is high, by some estimates 75% of processed foods. GE rice and alfalfa are also being tested in relatively large-scale plantings in the U.S. to study performance and assess impacts prior to commercial production.

Other smaller acreage crops have been genetically engineered, but are only being grown in small-scale field tests (most ≤ 20 acres). What kinds of small acreage crops have been grown commercially? In the early 1990's several fruit and vegetable products were commercially grown and entered U.S. (and some European) markets, FlavrSavr tomato, New Leaf Potato, high solids tomato, and Freedom Squash; most have been taken off the market. The only whole GE fruits or vegetables commercially available are papaya and squash, both engineered for viral resistance.

What kinds of GE crops are being developed and tested in laboratories and small-scale field trials? Many of these varieties are being developed in university laboratories. Examples include:



WHAT DO CONSUMERS REALLY THINK?

While much media attention focuses on safety questions related to GE foods, when asked to identify food safety concerns, few (1 to 2%) U.S. consumers list "altered or engineered food" as a concern. Certainly there have been a number of food and environmental safety issues raised regarding GE crops and foods. These issues must be carefully addressed. But efforts to resolve them should be proportional to the risk and should not overshadow addressing issues more relevant to solving the issues raised.

WHAT ARE THE ISSUES? FOOD SAFETY?

What are some of the food safety issues surrounding GE crops? One statement that is often made is that the GE foods we are eating today have not been tested for food safety. It is not true that they are not tested, but it is true that companies conduct this testing prior to commercialization, as occurs with drugs in the pharmaceutical industry. The data from these tests are then reviewed by federal agencies like the EPA and FDA. And this testing at present is voluntary. But the companies have the most to lose if a problem occurs - as happened with Starlink corn, which cost the company ~$2 billion. What kinds of tests are carried out? Nutrient equivalence testing is done to show that, for example, all vitamins, minerals, proteins, carbohydrates and fats are the same for GE and conventional food. Testing for toxicity and allergy-causing ability is also done.

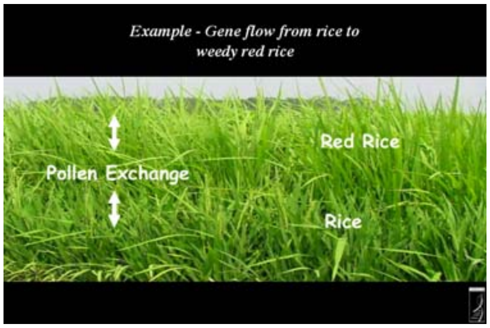
What about GE foods and allergies? One example raised is Starlink corn; products containing this GE variety were removed from the market in 2000. Starlink corn had an introduced gene that encoded a protein to protect it from insect damage. Based on examination of safety data by the federal agencies, the corn was permitted in animal feed but, until further testing and assessment was done, not for human consumption because of the possibility that it might cause human allergies. But the corn ended up in the food supply and some individuals claimed that they suffered allergic reactions to the corn. Subsequent tests of these individuals and the food they claimed caused the problem indicated none of problems were related to Starlink. But importantly this problem raised the issue of crop segregation. It has caused federal agencies to take a closer look at their policies.

Is the issue of food allergies limited only to the new GE foods? Let's look at the non-GE kiwi fruit, first introduced into the U.S. in the 1970's. At that time it was not known to be a food allergen. Today it is known that some individuals develop allergies to the fruit. In fact some people have cross allergies to latex rubber that could result in severe anaphylaxis, and in some cases death. So non-GE foods can cause allergies as well, but one question to consider is whether we should have done decades of testing on kiwi to predict this problem – a situation that some are suggesting for GE foods. A difficult question.

WHAT ARE THE ISSUES? ENVIRONMENTAL?

Movement of Genes into Wild Relatives. Could the passage of genes from GE crops to weed species lead to the development of a "superweed", one that does not respond to herbicides? Certainly the passage of genes from plant to plant will happen. In the U.S. major crops like soy, corn and cotton do not have wild relatives, but other crops like canola, sugarbeet, sunflower, rice and oats do have wild relatives and in some cases these relatives are control problems.

So is it possible that a gene could escape to the wild relatives? Yes, it is likely. Could this be a problem? It depends on the trait the gene is responsible for. To examine this issue, let’s look at



rice. Rice can cross with a plant called red rice, which can contaminate and reduce the value of cultivated rice. The movement of genes for Vitamin A enhancement, for example, from cultivated rice to wild rice would have little environmental effect. On the other hand, movement of herbicide tolerance would make it impossible to control red rice - with the herbicide used against the GE rice. It would not create a “superweed”, one that would not respond to all herbicides, but it would require farmers to return to practices used before the introduction of the GE varieties. We do need to be mindful of the consequences on the environment of what we do.

What about movement of genes in areas of plant diversity? The impact should be judged on a case-by-case basis, depending on the gene that is introduced. In areas of cultural diversity, crops with certain traits should not be released or the plants should be engineered to prevent passage of the trait to wild relatives. An example of genes escaping in an area of cultural diversity was raised by a report that Bt genes escaped into landraces of corn in Mexico, an area of cultural diversity for this important crop.

Movement of Engineered Genes into Organic Crops. Another possible impact of gene movement involves the passage of genes to organically grown crops. In the U.S. federal policy developed by organic farmers themselves states that GE crops cannot be designated as "organic". Therefore, although genes have moved from conventional crops to organic crops for years, movement of engineered genes from conventionally grown plants to organic plants can cause problems for organic farmers.

The question has been raised as to whether organic farmers will lose their certification if pollen from GE crops drifts onto organic plants and cross-pollinates. The National Organic Program regulations speak to the issue of "GMO contamination" of organic crops by genetic drift. "This regulation prohibits the use of excluded methods [which include GMOs] in organic operations. The presence of a detectable residue of a product of excluded methods alone does not necessarily constitute a violation of this regulation. As long as an organic operation has not used excluded methods and takes reasonable steps to avoid contact with the products of excluded methods, as detailed in their approved organic system plan, the unintentional presence of the products of excluded methods should not affect the status of an organic product or operation."

However, if a certifying agent suspects that an organic product came into contact with prohibited substances or were produced using excluded methods, the agent can call for testing, which under certain conditions could result in the product not being considered "organic." (National Organic Standards, subpart G, Administrative, sections 205.670 205.671). So, if GE cotton were grown near organically grown cotton, could this cause a problem? It is possible for the pollen (male cells) to flow from plant to plant and fertilize the eggs (female cells) of another plant, because of bees, and sometimes wind. But, according to the Organic Supervisor for the California Department of Food and Agriculture, Ray Green, if this occurs by accident, the grower will not lose his organic certification and can likely sell his product as organic.

Creation of Weeds Resistant to Herbicides. Certainly it is true that the use of certain herbicides has increased, the ones to which the GE crops are engineered to resist. In general these are more environmentally friendly herbicides but the overuse of single pesticides is likely to lead to, and already has led to, the development of herbicide resistant weeds. Was this surprising? Perhaps to some, but history has shown us that overuse of a particular herbicide can render a new chemical or technology useless. Will this situation create an ecological disaster? Not likely. Other perhaps less environmentally friendly herbicides can be used, but it will be a problem for companies developing the crops and farmers using them.

For more information and scientific references, visit the Biotechnology Information and Scientific Database sections of the ANR biotechnology workgroup website: http://ucbiotech.org