Crops, Genes, and Evolution

A RECENT STUDY on consumer attitudes toward genetically modified food shows that less than thirty-five percent of the people in six of ten European Union countries know that crop plants have genes. Apparently the remaining sixty-five percent believe the only crops that contain genes are those created by U.S. scientists working for multinational corporations. No wonder they're nervous about eating food derived from genetically modified crops.

Interestingly, for a number of decades, students in these same countries have routinely scored well on tests assessing scientific knowledge. How can we rectify these disparate facts? Do the EU citizens not know that food comes from living organisms, or have they simply forgotten that all living organisms, including those we eat, have genes? One conclusion is inescapable, however. The contradictory findings illustrate clearly how well insulated citizens in industrialized societies are from food production.

The recent debate about genetically modified foods says much about our love/hate relationship with technology, propensity for self-deception, and blasé acceptance of a constantly adequate food supply. For me, as a biologist, the debate also reiterates a lesson I continually re-learn: biologists view plants and animals, including those we eat, through a different lens than non-biologists. Our distinct viewpoint cannot be explained simply by knowing more biology, although understanding genetics and biochemistry certainly helps us assess food safety issues, and having a foundation in ecology and evolution allows us to evaluate the potential environmental risks of growing genetically modified crops.

The differences run deeper than having facts about biology at our disposal. As is true of all bodies of knowledge, at some point in its acquisition, with enough time and effort the knowledge becomes transformed into understanding. For biologists, the new understanding of nature imparts a very different view of the natural world and the place of our species in it. I am continually surprised by outcries of humans "playing God," as if such behaviors were new.

Left: An ear of teosinte, the presumed ancestor of corn, next to kernels from a modern hybrid corn variety. Selective breeding genetically transformed the wild relative of corn into domesticated corn.

As soon as we began growing crops and building shelters we began interfering with nature. Our distaste for the adversities nature indifferently dispenses has driven our continual quest for more technologies to insulate us from the natural world. We use all of these technologies for the same purpose: to change "God's" world so that it suits us better.

> "We have recently advanced our knowledge of genetics to the point where we can manipulate life in a way never intended by nature. We must proceed with utmost caution in the application of this new-found knowledge."
>
> — A critic of the famous plant breeder Luther Burbank, 1906

Evolution: Make Love, Not War

Theodosius Dobzhansky, the biologist who played an essential role in constructing the unifying framework of the life sciences, once said, "Nothing in biology makes sense except in the light of evolution." Is it any wonder, then, that biologists view the natural world and its organisms through the filter of evolution? Evolution depends on a two-step, circular process:

1. Creating populations of genetically diverse individuals, and
2. Culling certain individuals from that population, which is known in popular parlance as the "survival of the fittest."

The individuals left standing after the selection process produce the next group of genetically variable offspring that are subjected to a second round of culling, *ad infinitum*.

Because genetic variation is the grist of the evolutionary mill, nature has many mechanisms for generating genetically diverse populations, the primary one being sexual reproduction. Sex viewed through the evolution lens is nothing more than a form of genetic card-shuffling that creates diversity by combining existing genes in novel ways, not by creating new genes. Only mutation creates new genes.

"Survival of the fittest" relates more to sexual conquests and good parenting than to Tennyson's concept of "nature red in tooth and claw." In evolution, long-term survival does not necessarily equal fitness; survival is important only in the service of reproduction. The fittest organisms produce more offspring that, in turn, survive to reproductive maturity. If an organism excels at skills required for survival but leaves relatively few offspring, evolution deems it unfit. On the other hand, traits detrimental to survival can increase fitness if they improve mating prospects. Think of the peacock's tail. How could five feet of brightly colored, iridescent feathers improve survival? But peahens preferentially mate with males that have them, so males with long, brightly colored tails are the "fittest."

The Co-Evolution of Crop Plants and Human Societies

If chefs who are quoted in the popular press represent the mindset of the culinary community, then the prevailing assumption seems to be that farmers were growing "natural" crops, generously provided by Mother Nature, before scientists in white coats began to bioengineer them in the mid 1980s. Nothing could be further from the truth.

The crops grown for thousands of years did not exist prior to human intervention. We did not *discover* crop plants; we *invented* them. If "synthetic" is synonymous with concocted by humans and "natural" means provided by Mother Nature, then crop plants ceased being natural 10,000 years ago and, over time, have become increasingly synthetic.

For ninety-nine percent of the two to three million years we've existed, we lived as hunter-gatherers. According to archaeological records, around 8,000 B.C. we began cultivating the plants we had been gathering and, simultaneously, began genetically changing wild gathered plants into domesticated crops. "Domesticated," derived from the Latin word *domus* (house) and meaning "to bring into the house," is inseparable from the concept of genetic modification.

We selected certain plants with useful traits from a population of genetically variable plants and, in doing so, directed the evolution of wild, gathered plants into crop plants. At some point, the gradual shift from a hunter-gatherer economy based on food procurement to an agricultural economy based on food production became irreversible. Hunting and gathering could not sustain the increasing number of humans.[1] We became dependent on crop plants for our survival.

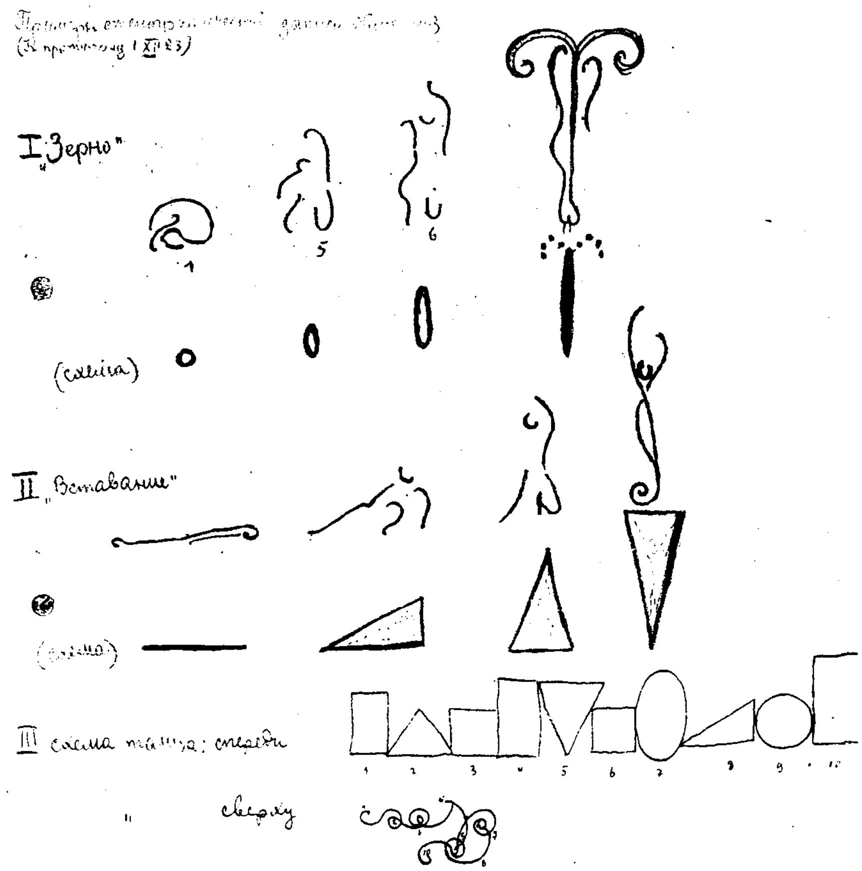
And they became dependent on us. The evolution of gathered plants from wild ancestral forms to domesticated crops became irreversible, as well. In the process of domesticating them, we changed their genetic makeup so significantly that they could no longer survive "outside of the house." In the terms of biologists, they were no longer "fit" because the reproductive needs of the plant conflicted with our own interests. The more we shaped a wild plant for human consumption, the less able it was to perpetuate itself.

Natural Evolution of Fruits and Flowers

In a word association test, a biologist would probably puzzle a psychologist by responding to "fruit" or "flower" with "reproductive mechanism." Fruit and flower production, which are interrelated, are relatively recent advances. If plant evolution were compressed into twenty-four hours, the capacity to produce flowers and fruits would appear at 10:30 PM. While we may egocentrically view fruits as food and flowers as decorations, for a plant they represent strategic means to one end: reproduction. Both are devices by which animals are induced, rewarded, tricked, and sometimes even seduced into carrying out the plant's reproductive mission.

Plants are, for the most part, immobile. They often rely on animals for uniting sperm (in the form of pollen) of one individual with eggs of another and for moving their offspring (seeds) away from home to avoid parent-offspring competition. Brightly colored flowers and fruits grab the attention of pollinators and seed disseminators and act as lures. Flower nectar, protein-rich pollen, and edible, fleshy fruits evolved as payments to animal visitors for transportation services. For certain plants that rely on animals to convey their seeds to distant locations, seed germination occurs only after a trip through the digestive tract of a bird or mammal.

Flowering plants are almost always hermaphroditic. More often than not a single flower contains both male and female organs; in others, such as corn and squash, separate male and female flowers occur on the same plant.[2] Fertilization with pollen produced by male flowers triggers fruit and seed formation from certain parts of the female flower. Although many hermaphroditic plants are capable of fertilizing themselves, out-crossing best meets a plant's need for creating genetically variable offspring. Consequently,



Aleksandr Larionov, "Birth of a Grain of Wheat." The idea of evolution has long engaged visionary artists as well as scientists. On December 1, 1923, the Russian choreographer Aleksandr Larionov used this drawing to illustrate a lecture on "An Experiment in the Field of Eurhythmics" at the Choreological Laboratory of the State Academy of Artistic Sciences in Moscow.

nature has provided plants with many mechanisms to facilitate cross-fertilization and others to impede self-fertilization. For example, in many flowers the pollen matures and is capable of successful fertilization before the female organs in that flower become receptive. A few flowering plants achieve the pinnacle of forced out-crossing by housing male and female flowers on different plants.

Human Interference in Plant Reproduction

Cross-fertilization may be in the plant's best interest, but humans are more concerned with higher yields than genetically variable plant offspring. Seed production tends to be higher and fruit set more certain in plants that can "self," because self-pollination does not depend on pollen transport by wind, insects, or other animals. Therefore, whenever possible, we have removed barriers to self-fertilization and discouraged cross-fertilization in our crops, such as wheat, rice, barley, peanuts, soybeans, peas, tomatoes, cotton, and beans.

When we compare domesticated fruits to their wild relatives, the most consistent, observable change is larger size. Selection for increased fruit size could lead to increased fitness, but a correlate of concocting fruits with more pulp was selection for fewer seeds. Creating varieties with fewer seeds directly conflicts with the evolutionary needs of a plant.

A wild tomato, which consists of a thin layer of skin packed full of seeds embedded in the familiar gelatinous material we associate with tomato seeds, is clearly a mechanism for making a new generation of tomato plants. Virtually one hundred percent of the internal volume is devoted to seeds; there is almost no pulp. Cherry tomatoes, which are primitive cultivated forms of wild tomatoes, are about twice as large as ancestral tomatoes and have four times more pulp and half as many seeds. A turn-of-the-century tomato variety is approximately twenty times larger than the ancestral wild tomato, and sixty percent of its internal volume is pulp. Finally, today's beefsteak tomato is ninety times larger than the ancestral wild tomato, and eighty-seven percent of its internal volume is pulp. We have not only created a tomato plant that devotes almost all of its energy to making fruit pulp for us and none to making seeds, we have also greatly increased the nutritional value of the fruit. The fruit pulp contains three times more vitamin C than the gelatinous material surrounding the seeds.

Humans have taken the trend to fewer seeds to an extreme by creating sterile varieties. Certain plants spontaneously mutated, creating cultivars able to produce fruit in the absence of fertilization. Examples include navel oranges, all modern cultivars of bananas and pineapples, and certain varieties of grapes, figs, and cucumbers. Because these mutants produced rudimentary seeds or none at all, in the wild these variants would have no future. Their genes would immediately be removed from the population by natural selection. However, we intervened in nature and propagated these varieties using vegetative reproduction (e.g., cuttings).

Genetic Modification to Decrease Seed Dispersal and Protection

It is in a plant's best interest not only to produce large numbers of genetically diverse seeds but also to have mechanisms for dispersing them over the greatest area possible. Widespread seed dissemination increases reproductive success by minimizing competition among young seedlings and also between the parent plant and its offspring. Some ripe fruits seem spring-loaded, bursting open with remarkable force.[5] Other plants, such as beggar's lice and sand spurs, rely on animals for seed dispersal and have velcro-like structures or barb-like appendages for attaching their seeds to fur and feathers.

Ripened ears of the wild relatives of our cereals shatter into individual seeds that are scattered widely by wind. Tension builds up in bean pods, which split in half along the seams, dispersing the seeds. But widely scattered seeds are difficult for us to harvest. One of the first genetic modifications we insisted on was no seed dispersal. Our cultivated cereals, such as wheat and corn, have rigid spikes of seeds that remain intact when ripe, as do the pods of our cultivated peas and beans. Cultivated varieties of oats, wheat, and rye lack the long, appendage-like, ancestral structures that enclosed the kernels and aided in seed dispersal of their wild ancestors because people selected seeds with the least amount of armature.

Wild cereals also have structures that protect the grain from damage and seed-eating animals—and also make it very hard to remove kernels from the plant. As a result, threshing is an arduous task that entails repeatedly beating stalks of grain. Any spontaneous mutation that lessened the need to thresh would have been highly valued by early agriculturists. Archaeological record shows very early selection for "free-threshing" varieties—mutants that readily released the kernel from its protective covering.

Removing a Plant's Means of Self-Defense

Most plants defend themselves against hungry insects with nasty chemicals, so many ancestors of our crops contained bitter, harmful, or even toxic chemicals. Plant gatherers developed preparation techniques that neutralized toxins and made plants palatable, such as leaching, roasting, and fermenting. The main function of the techniques many Asian cultures use in preparing various foods from soybeans is removal of substances that make untreated soybeans harsh and purgative.

Humans have created crop varieties with low levels of these distasteful and unhealthy chemicals. Lettuce, potatoes, cucumbers, spinach, beans, and cabbages contain only small amounts of the extremely bitter chemicals found in their ancestors. Home gardeners may have tasted a hint of the bitterness found in cucumber's wild relatives in cucumbers grown during dry spells. In selecting for crops with low levels of bitter or toxic chemicals, we stripped plants of their ability to defend themselves. Improving the taste of our crop plants also made them tastier to insect pests. Hence the need for external pest control measures.

Our genetic modifications have been specifically targeted to plant parts of interest to us. The castor oil plant contains a very deadly poison, ricine, in its seeds. When the seeds are pressed, the poison does not come out in the oil, which is used for cooking in the Far East. Therefore, humans have not bothered to create a non-toxic variety. A similar situation exists for Indian mustard, which has large amounts of toxic sulfur-containing oils. The insignificant amount of toxins in the oil from pressed seeds means no one has bothered to breed nontoxic varieties. However, the high amount of toxic oils left in the residue after pressing prevents it from being used as livestock feed.

By focusing selection efforts very precisely, we tailored crops for specific purposes. This pattern is seen clearly in different beet cultivars. The wild ancestor of beets has large amounts of two chemicals that impart an unpleasant, bitter taste. Beets grown for industrial extraction of raw sugar are never eaten, and they have considerable amounts of these two chemicals. Beets fed to livestock contain much lower levels, while garden beets eaten by human are almost free of these undesirable elements.

The Evolution of Genetic Modification Techniques

Selective Breeding: Incorporating Existing Genetic Variation

Genetic diversity in plants has been a valuable natural resource humans have exploited for centuries. Certain plants in a population had traits, and therefore genes, we valued, and we chose them to serve as parents for the next generation. By selecting certain genetic types and excluding others, we radically changed the genetic makeup of the crops we domesticated (See photo of teosinte p.20).

Many people view plant breeding as natural. However, over the last one hundred years, humans have crossbred plants that would never have been able to hybridize without human interference. Many of these "wide crosses" involve plants belonging not only to different species but also to different genera, the next level of genetic difference (Table 1). For example, bread wheat has been crossbred with more than ten different species in four different genera, so any one bread wheat variety contains genes from a number of different species. We pushed the breeding envelope in order to incorporate certain traits into our crop plants (Table 2) and vaulted natural reproductive barriers by using increasingly sophisticated laboratory techniques developed over the last century (Table 3).

Therefore, rejection of the newest genetic modification techniques because they are unnatural is misplaced. We began creating "unnatural" varieties of all of our major crops decades ago.

Table 1. Examples of crops that are in the same family but different genera.

The ability to move genes across the species barrier is not unique to genetic engineering. Plant breeders have crossbred plants belonging to different genera, but the same taxonomic family.

FAMILY: ROSACEAE	FAMILY: SOLANACEAE
Apple	Potato
Almond	Tobacco
Strawberry	Tomato
Peach	Eggplant

Mutagenesis: Creating New Genetic Variation

Certain desirable traits cannot be found in gene pools accessible through plant breeding, even when implementing the unnatural crossbreeding tricks of the trade described in Table 3. In the 1940s we began to create new genes in our crops and their relatives using mutagenic agents such as X-rays, gamma rays, and various chemicals. These mutagens induce genetic changes on a completely random basis. Nonetheless, we have used mutagenesis successfully to give new, desirable traits to more than 1550 crop varieties, including certain varieties of wheat, soybeans, rice, corn, peanuts, oats, peas, beans, sunflowers, canola, tomatoes, and potatoes, to name just a few.

Table 2. Interspecific and intergeneric hybridizations through breeding.

Since the early 1900s plant breeders have produced many crop cultivars by forcing hybridizations between plants that cannot interbreed naturally. As a result, many crop cultivars grown internationally for decades were created by crossing plants in different species and also different genera. This table provides selected examples of crops developed using between-species and between-genera hybridizations and the traits transferred into the crop species through the hybridizations.

CROP SPECIES	TRAIT
Corn	fungal disease resistance
Canola	altered fatty acid ratios
Oats	increase yield 25–30%
Beets	nematode resistance
Tomato	virus resistance; harvesting traits; nematode resistance; fungal disease resistance
Rice	virus resistance
Potato	fungal disease resistance; virus resistance; insect resistance; nematode resistance
Wheat	fungal disease resistance; increase protein; insect resistance; drought tolerance; winter hardiness

Genetic Engineering: Accessing All of Nature's Genetic Diversity

The term "recombinant DNA technology," or genetic engineering, refers to the newest genetic modification techniques that allow us to move single genes into existing crop varieties. No reproductive barriers exist at the molecular level, so our crop improvement capabilities are no longer restricted to the small pool of genetic variation within which we can manipulate plant breeding. A desirable gene from any organism may theoretically be placed in a crop, no matter how distantly related the two are, because at the level of the gene, all living organisms speak the same language. Genetic engineering gives plant breeders access to all of nature's astounding genetic diversity.

Table 3. Laboratory techniques for crossbreeding plants that do not hybridize naturally.

During the last half of the twentieth century, plant breeders developed increasingly sophisticated laboratory techniques for crossbreeding plants in different species. The table below provides a few examples of natural physiological barriers to hybridization and the techniques plant breeders have used to overcome the barriers.

	BARRIER	TECHNIQUES FOR OVERCOMING THE BARRIER
Pre-Fertilization Barriers	Failure of pollen germination	Remove pistil then pollinate exposed end
		Use recognition mentor pollen
	Slow pollen tube growth	Chemical treatment with organic solvents or growth regulators
	Pollen tube growth stops	*In vitro* fertilization Use of plant growth hormones and chemicals like chloramphenicol and acriflavin
	Failure to obtain sexual hybrids	Protoplast fusion
	Different number of chromosomes	Chemically induce chromosome doubling
Post-Fertilization Barriers	Embryo abortion (immediate)	*In vivo/vitro* embryo rescue/implantation
	Embryo abortion—early stages of development	Culture ovaries in petri dishes
	Lethality of F_1 hybrids	Use cell culture to regenerate plants
	Chromosome elimination	Alter genomic ratios of species Induce chromosomal exchanges with tissue culture or irradiation
	Hybrid sterility	Chemically induce chromosome doubling

Comparing Selective Breeding, Mutagenesis, and Genetic Engineering

Comparative Risks

Genetic engineering and selective breeding utilize existing genetic diversity to create crop varieties with useful new traits. Even though genetic engineering and selective breeding bear a fundamental resemblance to one another, they also differ in important ways (Table 4). In genetic engineering we move single genes, whose function we know, into crop varieties with which we have extensive experience. In selective breeding, thousands of genes of unknown function are transferred from wild relatives back into our crop cultivars. Some of these genes are responsible for undesirable traits that we removed from crops thousands of years ago. So plant breeders must spend ten to twelve years re-removing these genes through back-crossing. Nonetheless, thousands of genes of unknown function remain in crop cultivars created through selective breeding when they enter the marketplace.

Table 4. Differences in selective breeding and genetic engineering.

PARAMETER	SELECTIVE BREEDING	GENETIC ENGINEERING
Level	Whole organism	Cell or molecule
Precision	Thousands of genes	Single gene
Certainty	Genetic change poorly characterized	Gene well-characterized; identity of new protein is known
Taxonomic Limitation	Usable within and between species; sometimes between different genera	None

When we use mutagens to create new genes in our crops or their relatives, we undoubtedly change other genes in addition to those for the desired trait. We have no idea which genes, or how many genes, of the tens of thousands of plant genes also mutate in response to treatment with radiation and chemicals. New crop varieties are tested for certain traits recognized to be relevant to food safety and nutrition (described below). Even though mutations may have also occurred in scores of genes, because their functions are unknown, we do not know which additional variables to measure.

Therefore, genetic engineering is more precise and predictable than any of the other genetic modification techniques that have been used to create the crops we have eaten for all of our lives. By increasing the precision and certainty of our genetic manipulations, the risk of producing organisms with unexpected traits decreases. Genetic engineering allows us to circumvent the trial-and-error approach of selective breeding and randomness of mutagenesis.

Virtually every scientific body that has published a report or position paper[4] on the risks and benefits of genetically engineered crops has come to the same conclusion: *The risks associated with crops genetically modified by the newest techniques (i.e., recombinant DNA techniques) are essentially the same as the risks of crops genetically modified by the techniques we have used for centuries.* For decades, farmers throughout the world have grown crops genetically modified, through crossbreeding and mutagenesis, to be insect-resistant, disease-resistant, drought-resistant, and herbicide-tolerant, so we have abundant data for assessing the potential risks of crops genetically modified with recombinant DNA techniques. Nature does not care how the gene got into the plant, but only what the gene does.

The Ethics of Genetic Modification

Some people have objected to the ethics of genetic engineering because it allows us to move genes between organisms that would never interbreed in nature. However, as described above, plant breeders created certain varieties of all of our major crop plants by forcing unnatural hybridizations. The criterion of naturalness, or lack of it, provides no clear boundary for distinguishing genetically engineered foods from foods we have consumed for decades. If we decide we should not move genes between organisms that are "too different," how will we define "too different"? Where will we draw the line, and why will we draw it there?

In answering—or even asking—these types of questions, differences in biologists and non-biologists come into sharp focus. Non-biologists seem to view Mother Nature as a tidy housekeeper with a "place for everything and everything in its place." Species are seen as discrete, well-defined units with very clear borders separating one from another—like a box of eight crayons where green and blue are easy to distinguish.

When biologists look at the natural world, we see a continuum of types—all of the shades between green and blue. All species are both genetically alike and genetically different from one another. Both genetic unity and genetic diversity characterize all of the earth's species. Within a species, the same is true: all individuals of a species (or a population) are genetically alike and genetically diverse. Because a continuum of genetic variation/similarity exists within a species and extends outside of a species to related species, determining where one species stops and another begins can be difficult and, at times, arbitrary. Where one chooses to demarcate a species boundary is flexible and, more often than you might expect, subject to lively debate among biologists. Some people look at a teal crayon and see green while others see blue.

Because of the genetic continuum that extends within and across species, there is no one gene that makes a fish a fish and an oak tree an oak tree any more than one gene that I have and you don't makes me more human than you.

Useful Facts for Assessing the Risks of Genetically Modified Food

Genetic modification of food by humans is not new. We have genetically modified virtually all of the food we have ever consumed.

Much of our genetic modification has been through "unnatural" means. We began cross breeding plants in *different species* over 100 years ago. We have even crossbred plants in *different genera*—a greater degree of genetic difference than separate species.

Insect-resistant crops and disease-resistant crops are not new "inventions" of biotechnology. We have eaten and farmers have grown genetically modified insect-resistant and disease-resistant crops for decades.

Farmers began using herbicides and herbicide tolerant crops around 50 years ago. Over 95% of the corn and soybeans grown in the U.S. since the 1970s have been herbicide-tolerant varieties.

For decades seed companies have introduced new crop varieties into the food supply annually, all of which differ genetically from those grown and consumed during the previous years. These varieties were created using genetic modification techniques that are less precise and predictable than genetic engineering: selective breeding and mutagenesis.

FDA *will* require labels for any food product, produced through genetic engineering, that

- contains a gene from a known food allergen
- has a nutritional content that differs from its "parent."

The FDA and Genetically Modified Crops

Food Safety and Nutritional Value

Virtually every year for the last century, scores of new genetic varieties of crop plants have come to market. The U.S. Food and Drug Administration (FDA) has oversight responsibility for the safety of foods and animal feeds derived from new crop varieties. Before a new variety can be sold in the United States, seed companies must conduct extensive studies on the crop's biochemistry and nutritional value, irrespective of the type of genetic modification technique used to create it. The level of macronutrients and micronutrients must equal the currently marketed crop varieties, or else the new crop and its derivative products must be labeled as such. Additional crop-specific tests are also performed. For example, companies must determine the solanine content of new potato varieties because plant breeding, mutagenesis, or genetic engineering may have unintentionally increased the levels of this natural potato toxin. New soybean varieties are assessed for changes in soybean-specific substances related to health and nutrition, such as the soy proteins that are known allergens, the phytoestrogens, genisten and daidzein, and the naturally occurring, anti-nutritive enzyme inhibitors found in raw soybeans.

In addition to this standard battery of tests for all new crop varieties, those created through the new genetic engineering techniques are subjected to additional tests. Ironically, the FDA requires these additional tests *not* because they believe these crops are less safe but simply because, in the case of genetically engineered crops, we know what to test! As described earlier, in genetic engineering we move one gene of known function into an existing crop cultivar. We know the chemical makeup and the function of the protein that will be added to the cultivar by this new gene. As a result, we subject crops that are genetically modified with more precise and predictable techniques to more stringent regulation than those created by the more random and less predictable techniques of selective breeding and mutagenesis.

Labeling Genetically Modified Foods

The FDA's responsibility is consumer protection. As such, it mandates labeling for any food product that raises concerns related to human health and food safety. The statutes under which the agency operates require the FDA to ensure that food labels are accurate, do not mislead, and contain information on nutrition and food safety that is important for consumers. The current FDA labeling policy for foods derived from genetic engineering is consistent with this statutory mandate. If a food's nutritional value or potential to cause an allergic reaction changes as a result of genetic engineering, the FDA requires food companies to put that information on a food label.

Because humans began to genetically alter our food crops centuries ago, labels describing a food as "genetically modified" would be misleading and inaccurate—unless virtually all foods on the market carried the same label. Nor would such a label provide any information that is relevant to human health or food safety. Mandating labels that are inaccurate, misleading, and not informative is *not* a precedent the FDA should set.

Evaluating Arguments about Genetically Engineered Crops

The media's treatment of genetic engineering in agriculture often gives the impression that the scientific community is deeply divided on the risks of this newest generation of genetically modified crops. This simply is not true. As described above, a remarkable amount of scientific consensus on this issue exists, but I suppose reporters think lack of conflict does not constitute a good story. It seems that the prime ingredients of a good story these days are fear and conflict.

My training as a scientist provides its greatest benefits every time I read a media report on the potential risks of genetically engineered crops and my pulse begins to race with fear. But, once again, the advantage of being a biologist comes not from what I know but from how I think. To me, the greatest value of scientific training is a proclivity for asking questions without being emotionally attached to a specific answer—a willingness to look objectively at data even if the facts contradict our preconceived notions.

WHEN FACED WITH the next frightening story on the risks of genetically engineered foods, I encourage you to ask these same questions while maintaining a non-partisan sense of detachment.

Do we have relevant experience with similar crops genetically modified through selective breeding and mutagenesis?

What, if anything, is unique about this particular genetically engineered crop?

Is this an improvement over current agricultural practices?

You may be surprised at how quickly your pulse rate returns to normal. ⊚

NOTES

1. One hunter-gatherer requires 20 km²; the same area can sustain 6,000 people if crops are grown. If humans had continued as hunter-gatherers, the maximum population size would have been twenty to thirty million.

2. This explains why using squash blossoms as food does not necessarily decrease production of squash. But you must pick male, and not female, flowers and also leave at least one male blossom!

3. An example that may be familiar to readers is the fruit of flowering impatiens plants.

4. Among the scientific organizations that have released comprehensive studies (and the number of studies released) are the U.S. National Academy of Sciences (3), American Medical Association (2), International Academy of Sciences, representing scientists from thirteen countries (1), FAO/WHO (4), American Dieticians Association (1), U.S. Office of Technology Assessment (2), and the Ecological Society of America (1).