The Genetically Modified Crop Debate in the Context of Agricultural Evolution

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"Whoever could make two ears of corn, or two blades of grass grow upon a spot of ground where only one grew before would deserve better of Mankind, and do more essential service to his country, than the whole race of politicians put together."
— The King of Brobdingnag, *Gulliver's Travels* by Jonathan Swift, 1727.

"I believe that we have now reached a moral and ethical watershed beyond which we venture into realms that belong to God, and to God alone. Apart from certain medical applications, what actual right do we have to experiment, Frankenstein-like, with the very stuff of life? . . . "
— Prince Charles Windsor, heir to the British throne (Windsor, 1998).

Throughout the history of humankind, there have been those who have embraced change and those who have clung to the old ways because they felt at least the risks were known. Few Edisons or Einsteins were properly recognized during their lifetime. And, since feeding ourselves was the primary occupation of mankind for most of our recorded and prerecorded history, changes in food production have been accepted slowly. The first person to try to scratch out a garden most assuredly heard derisive laughter as the mighty hunters headed off in pursuit of meat. So, we should not be surprised that eons of history are being replayed as we enter the era of biotechnology. As the fates of human society and crops have been inextricably intertwined since the dawn of civilization, an appreciation of our agricultural past may guide us in addressing societal concerns and also in ensuring minimal negative consequences from scientific pursuits.

Farmers have embraced the new technology because it makes them more efficient, protects or increases yields and reduces their reliance on chemicals that, other things being equal, they would prefer not to use. Crops enhanced by biotechnology are being grown on nearly 110 million acres in 13 countries. Food ingredients produced from biotech crops are found in thousands of food products consumed worldwide. However, while no unequivocal evidence of harm to our health or the environment from these crops is known or expected, there is an intense debate questioning their value and safety.

Societal anxiety over this so-called genetically modified (GM) food is understandable, and it is fueled by a variety of causes, including consumer unfamiliarity, lack of reliable information on the current safeguards in place, a steady stream of negative opinion in the news media, opposition by activist groups, growing mistrust of industry, and a general lack of awareness of how our food production system has evolved. The scientific community has neither adequately addressed public concerns about GM foods nor effectively communicated the value of this technology. Clearly, societal acceptance is pivotal to the continued development and application of biotechnology in food and agriculture.

Two decades ago, many agricultural scientists rightfully saw the emerging recombinant DNA technology as a potent tool in enhancing crop productivity and food quality while promoting sustainable agriculture. Much of this early excitement and expectation was met with successive breakthroughs in scientific research on plant gene transfer methods, identification of valuable genes, and the eventual performance of transgenic crops. Plant breeders saw the technology as an additional means of crop improvement that could complement existing methods. For the first time, plant breeding was subjected to rigorous testing, and a regulatory framework was developed to oversee the commercialization of GM crops on a case-by-case basis. There has been widespread acceptance and support for biotechnology from the scientific community. Accumulated experience and knowledge of decades of crop improvement combined with expert judgment, science-based reasoning and empirical research has led to scientists' confidence that GM crops may pose no new or heightened risks that could not be identified or mitigated, and that any unforeseen hazard will be negligible, manageable, or preventable. Risks from GM crops should be monitored and measured, but concerns about these risks must also be balanced against the enormous benefits from this technology and weighed against alternative options. The strong trust that the American public has in its regulatory agencies (FDA, USDA, and EPA) has helped gain higher public acceptance of GM food in this country than in other nations.

MUTANT FOOD AND MONARCH BUTTERFLIES

Despite the promised benefits, global negative reaction to GM crops ranges from mild unease to strong opposition. Typical questions asked about GM crops include: Is it ethical for scientists to modify living organisms around us? Is it morally right to

tamper with our food supply? Is the genetic modification of crops inherently hazardous? Despite the built-in safeguards, can we unwittingly make our foods unsafe? What about the long-term consequences of consuming such foods? Do GM crops affect the environment or the wild ecosystem, reducing crop biodiversity, beneficial insects, or the revered monarch butterfly? Could these crops lead to the development of noxious "superweeds"? Are we introducing these crops into our environment without fully understanding the consequences of such action? What about genetic pollution? Can these genes be transferred to other organisms including humans and animals? In addition, there are also larger and even more important sociopolitical issues such as anxiety about the control of food and agricultural systems, including questions about the pervasive impact of globalization.

How can scientists allay public concerns considering the complexities of these issues? Creating an awareness of agricultural history may provide a good beginning for our efforts to help alleviate consumer unease about GM foods. It may also educate scientists about the relevance of the societal context to our research. Most risk issues related to current GM crops are not unique when placed in the context of how agriculture was developed through crop domestication over many millennia and how we have bred modern crop varieties in the past century. As Frary and Tanksley (2000) put it, "The issue is not whether we should modify the genetics of crop plants. We embarked on that road thousands of years ago when plants were first domesticated. Instead of simply judging the vehicle through which we make genetic changes, we need to weigh the potential consequences that such modifications hold for the society and the environment."

CROP EVOLUTION AND HUMAN CIVILIZATION

Agriculture evolved independently in many places on this earth, but the earliest evidence of farming dates 10,000 years ago in present day Iraq (Heiser, 1990). For much of the 200,000 or so years prior to agriculture, humans lived as nomadic hunters, gatherers, and scavengers surviving solely on wild plants and animals. Subsequent domestication of these wild plants and animals from their natural habitats launched agriculture, thus radically transforming human societies. This occurred initially in the Fertile Crescent, the Andean region in South America, Mexico, and parts of Asia, but diffused throughout much of the globe. A change from the nomadic lifestyle to farming led us to become community dwellers, eventually spawning the development of languages, literature, science, and technology as people were freed from the continuous daily task of finding food. Some regions caught on much faster than others, by margins of thousands of years (Diamond, 1999).

Plants have also evolved or, more accurately, they have been changed rapidly by human intervention (Harlan, 1992). Every crop plant grown today is related to a wild species occurring naturally in its center of origin, and progenitors of many of our crops are still found in the wild. Early humans must have tried eating thousands of feral plant species from a pool of a quarter of a million flowering plants before settling down on less than one thousand such species, which were subsequently tamed and adapted to farming. A little over 100 crop species are now grown intensively around the world, with only a handful of them supplying us with most of what we now eat. Through a process of gradual selection, our ancestors chose a very tiny section of the wild plant community and transformed it into cultivated crops. Some profound alterations in the plant phenotype occurred during such selection, and these include determinate growth habit; elimination of grain shattering; synchronous ripening; shorter maturity; reduction of bitterness and harmful toxins; reduced seed dispersal, sprouting and dormancy; greater productivity, including bigger seed or fruit size; and even an elimination of seeds, such as in banana. These changes reduced the survivability of crops in the wild, and thus a feature that transcends all of our crops is the reduction of weedy traits from wild plants. Present crops are thus totally dependent upon human care for their survival, and modern crop varieties would persist in the wild "no longer than a Chihuahua would last in the company of wolves" (Trewavas, 2000).

Most crops that supply our food were thus obtained at the end of the Stone Age, often from a relatively narrow pool of extant wild genetic diversity. Additional diversity arose within such cultivated crops through new mutations and natural hybridization, and through judicious selection and perpetuation by farmers who maintained them as land races. Varied uses and preferences brought forth further diversification such as in corn (popcorn, sweet corn, dent corn, broom corn, and flour corn for tortilla and corn bread) or the derivatives of ancestral cabbage (kale, kohl rabi, brussels sprouts, cabbage, cauliflower, and broccoli).

With the advent of transoceanic navigation and the "discovery" of the New World, crops were moved around the world rapidly, often achieving prominence in adopted homes far beyond their natural centers of origin or domestication. For instance, the United States is the leading producer of corn and soybean in the word, yet these crops are native to Mexico and China, respectively. The world's largest traded commodity, coffee, had a humble origin in Ethiopia, but now much of it is produced in Latin America and Asia. Florida oranges have their roots in India, while sugarcane arose in Papua New Guinea. Food crops that are now so integral to the culture or diet in the Old World, such as the potato in Europe,

chili pepper in India, cassava in Africa, and sweet potato in Japan, were introduced from South America. For that matter, every crop in North America other than the blueberry, Jerusalem artichoke, sunflower, and squash are borrowed from elsewhere!

A few sources of our food are also recent domesticates. Chinese gooseberry occurs wildly in China and is not edible. But careful breeding made it palatable, and it was re-christened "Kiwi fruit" in New Zealand after its introduction there early in the 20th century. The modern strawberry with big fruits is a product of the accidental crossing of two wild species from Virginia (United States) and Chile in France in the mid-18th century. Rapeseed, grown in India for centuries, was altered recently through classical breeding to eliminate the toxic erucic acid and smelly glucosinolates to result in canola—Canadian oil. Triticale, a completely new crop, was artificially sythesized a few decades ago by combining the genomes of wheat and rye (two distinct genera that do not interbreed in nature). It is now grown on over three million acres worldwide. Modern bread wheat itself is also a fairly recent crop in the evolutionary time scale, having arisen only about 4,000 years ago through hybridization of tetraploid (pasta or durum) wheat with inedible goat grass.

FROM MESOPOTAMIA TO MENDEL

While humans have always molded the evolution of crop plants, such changes imposed by farmers occurred over several millennia, leading to rich crop diversity—especially in traits related to their planting or consumption. At the same time, global population grew very slowly until the mid-19th century. It took 1,800 years for the global population to climb from an estimated 300 million around the time when Christianity began, to reach its first billion. But it took only 12 years to add the last billion, rising from five billion people in 1987 to six billion two years ago.

Fortunately, parallel scientific developments in agriculture ensured that food production kept pace with the population explosion of the past century (Conway, 1999). Beginning with Mendel's study of peas, knowledge of genetics helped usher in scientific crop development, resulting in high-yielding varieties. Food production increased in every part of the world in the past few decades, including in Africa. Per capita food consumption has also increased steadily everywhere except in parts of sub-Saharan Africa. In the United States and Canada, where such scientific developments and their applications were most intense, one average farmer now produces enough to feed nearly 150 people! In crops subject to intensive scientific attention—corn, wheat, and rice—the productivity levels increased severalfold. For example, U.S. corn growers averaged 26 bushels of corn per acre in 1928 and 134 bushels per acre in 1998 (National Corn Growers Association, 2001).

Such a prodigious increase in agricultural production was underpinned by scientific crop improvement methods along with other developments, including the use of irrigation, improved soil fertility management, mechanization, and control of diseases and pests (Conway, 1999). To develop better crop varieties, scientists have used an array of tools. Artificial crossing, or hybridization, helped us assimilate desirable traits from several varieties into elite cultivars. When desired characteristics were unavailable in the cultivated plants, genes were liberally borrowed from wild relatives and introduced into crop plants. When a crop variety refused to mate with the wild species, various tricks were employed to force them to intermingle, such as the use of the carcinogenic chemical colchicine or by rescuing the hybrid embryos with tissue culture methods. Hybrid vigor was exploited in crops such as corn and cotton to boost productivity. When existing genetic variation within the cultivated germplasm was not adequate, breeders created new variants using ionizing irradiation (gamma ray, x-ray, neutron), mutagenic chemicals (ethyl methane sulfate, mustard gas), or through somaclonal variation (cell culture).

Most people who are concerned about modern biotechnology have little or no knowledge of the processes that have been used to transform crops in the past. Nor are they likely aware that crops have been continually altered over time or that, without human care, they would cease to exist. Using a variety of tools over the past few decades, plant breeders have radically transformed our crop plants by altering their architecture (such as the development of dwarf wheat and rice), shortening growing seasons, developing greater resistance to diseases and pests (all crops), and developing bigger seeds and fruits (Figs. 1 and 2). These crops are also more responsive to management and better adapted to diverse ecological conditions. Improved food quality also resulted through fewer toxins (canola), better digestibility (beans), increased nutrition (high-protein corn), better taste, longer shelf life (thus withstanding long transportation and storage), and enhanced freshness in many vegetables and fruits. A 1,000-fold increase in the marble-sized wild *Lycopersicon* resulted in the modern tomato that can now weigh as much as a kilogram (Frary and Tanksley, 2000).

Modern farming has steadily increased the supply of relatively safe, affordable, and abundant food not only in the developed world, but also in most developing countries. An average American family now spends only 11% of its income on food and yet has access to better food choices with more variety and nutrition than ever before. Without scientific developments in agriculture, we would otherwise be farming on every square inch of arable land to produce the same amount of food!

Using gene transfer techniques to develop GM crops thus can be seen as a logical extension of the

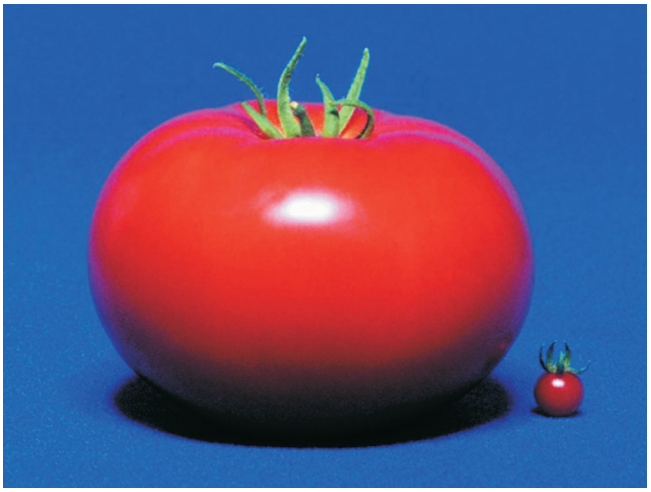

Figure 1. Cultivated tomato (left) and its wild relative *Lycopersicon pimpinellifolium* (right; approximate diameter of smaller tomato = 1 cm). (Photo kindly provided by Steve Tanksley.)

continuum of devices we have used to amend our crop plants for millennia. When compared to the gross genetic alterations using wide-species hybridization or the use of mutagenic irradiation, direct introduction of one or a few genes into crops results in subtle and less disruptive changes that are relatively specific and predictable. The process is also clearly more expeditious, as the development of new cultivars by classical breeding typically takes from 10 to 15 years. The primary attraction of the gene transfer methods to the plant breeder, however, is the opportunity to tap into a wide gene pool to borrow traits, obviating the constraints of cross-compatible crop species.

ADDRESSING PUBLIC CONCERNS

While direct gene transfer is still a relatively new approach, many concerns arising from its use may be addressed with the "benchmark" of conventionally bred varieties, as we have the accumulated experience and knowledge with the latter for more than a century. While it seems logical to express a concern such as "I don't know what I am eating with GM foods!" it must be remembered that we really never had that information before with classically bred crops. With GM crops, at least we know what new genetic material is being introduced, so we can test for predictable and even many unpredictable effects. Consider, for example, how conventional plant breeders would develop a disease-resistant tomato. They would introduce chromosome fragments from its wild relative to add a gene for disease resistance. In the process, hundreds of unknown and unwanted genes would also be introduced, with the risk that some of them could encode toxins or allergens, armaments that wild plants deploy to survive. Yet we never routinely tested most conventionally bred varieties for food safety or environmental risk factors, and they were not subject to any regulatory oversight. We have always lived with food risks, but in the last few decades we have become increasingly more adept at asking questions.

To address the concern about long-term health consequences of GM foods, it is instructive to recognize that we worried little about such impacts when massive amounts of new proteins (and unfamiliar chemicals) were introduced into our foods from wild species or when unknown changes were created through mutation breeding. When new foods from exotic crops are introduced, we often assimilate them easily into our diets. What's more we rarely, if ever, before asked the same questions that we now pose about GM crops. Many so-called functional foods, health foods, and nutraceuticals have been entering into the mainstream American diet lately, with little or no regulation or testing. We do not question the long-term health implications of these food supple-

Figure 2. Modern corn hybrid (right), its wild relative teosinte (left), and their hybrid (cob in the center). (Photo kindly provided by John Doebley.)

ments, even though they involve relatively large changes in our food intake. In contrast, the GM foods currently on the market have been tested extensively and judged to be substantially equivalent to their conventional counterparts, with just one or two additional proteins present in miniscule amounts (introduced into a background of thousands of proteins). And, those proteins are broken down either during processing or digestion, with little long-term consequence. In food products such as oil, starch, and sugar, such proteins are not even found. A nagging potential problem with a new protein in food is that it could be a potential allergen. As most food allergens are now well studied, we know that they are found in few defined sources (peanut and other grain legumes, shellfish, tree nuts, and a handful of other foods) and share many similar structural features. Moreover, they must be present in huge proportions in our food, and we must be sensitized to them over time for them to cause any adverse effects. Thus, it is highly unlikely for new allergens to be introduced into our food supply from GM plants.

HISTORICAL ABSENCE OF ZERO RISK

There is no such thing as safe food, and there never has been! That is not to suggest that all of our foods are dangerous, only an acknowledgment that trace levels of such contaminants as toxins and carcinogens are present in everything we eat. But a primary rule of toxicology, articulated over 400 years ago by Paracelsus, refers to the importance of dosage: "Every substance is a poison, but it is the dosage that makes it poisonous" (Poole and Leslie, 1989).

While not alarming, our daily food naturally contains thousands of chemicals, and many of them are shown to be carcinogenic or hazardous in lab animal studies with huge doses. We consume roughly 5,000 to 10,000 natural toxins daily, as plants have evolved to produce an array of chemicals to protect themselves against pests, diseases, and herbivores (Ames et al., 1990a). For instance, roasted coffee has over 1,000 chemicals, of which 27 have been tested and 19 of them found to be rodent carcinogens (Ames and Gold, 1997). The fat-soluble neurotoxins solanine and chaconine are present in potatoes and can be detected in the bloodstream of all potato eaters (Ames et al., 1990b). Naturally then, when crops are bred for resistance to pests by transferring genes through conventional methods, the resistance is often accompanied by an increase in such toxic compounds.

Thus, it is not true that we never had problems with conventionally bred varieties. Any crop variety found to pose a real health risk was promptly removed from the market, but those varieties (in contrast to GM crops) were never routinely tested. One pest-resistant celery variety produced rashes in agricultural workers and subsequently was found to contain 6,200 ppb of carcinogenic psoralens compared to 800 ppb in the control celery (Ames et al., 1990). This celery was removed from cultivation and that was also the case with the potato variety Lenape, which contained very high levels of toxic solanine.

We have always learned from trial and error with all innovations. Similarly, crop improvement practices evolved over time with continued refinement. It is common, though, for human nature to generate an exaggerated fear of new innovations while perceiving older or "natural" products as always more benign. Huber (1983) discusses this double standard in the larger context of risk regulation. We have always been lenient toward existing known and greater hazards, even as we create "gatekeepers" to minimize new risks. Thus, we fail to recognize and "exorcise" much larger older risks.

While most food hazards arise from pathogens such as *Escherichia coli* 0:157, *Listeria monocytogenes*, and *Salmonella enterica* along with mycotoxins produced by fungi (and thus a function of food storage and handling), certain foods containing toxic compounds are known to produce adverse health consequences over time. Cassava, eaten by a large population in Africa, contains cyanogenic glucosides, which cause limb paralysis if consumed before extensive processing. Solanin in tomato and potato is known to cause spina bifida. Vetch pea, a common legume known for its hardiness—and thus popular in India among poor farmers—contains highly dangerous neurotoxins that cause untold misery. Phytohemagglutinin, found in undercooked kidney beans, is toxic. And peach seeds are extremely rich in cyanogenic glucosides. None of these were subject to any mandatory testing before they were introduced into the food chain, nor are they subject to any regulation now. But if the current regulatory standards imposed on GM crops were to be invoked for traditional crops, most of them would fail to meet their requirements.

Humans have built-in natural defenses that protect us against normal exposure to toxins. But, according to Ames and Gold (1997), we have not evolved to achieve "toxic harmony" with everything we eat, because natural selection occurs much too slowly and because much of what is in our diet today was not eaten at all when we were hunter-gatherers.

A balanced mixture of foods normally provides adequate nutrition. However, none of the crops grown today were selected with our nutritional requirements in mind. Instead they were chosen intuitively, by our ancestors, from among the edibles that could be found around them. Thus, the most important food crop in the developing world—rice—has no provitamin A and little iron in its endosperm. This has led to horrific problems, such as blindness among millions of children due to vitamin A deficiency, and iron-deficiency anemia in nearly a billion women dependent on a rice diet. Biotechnology research, far

from causing any new food safety problems, has already demonstrated its potential in enhancing the nutritional quality of our food and is also being employed to reduce harmful toxic compounds that exist in our food.

WHAT ABOUT THE ENVIRONMENT?

All of us have to eat to live, and organized food production is the most ecologically demanding endeavor we have pursued. Agricultural expansion over the millennia has destroyed millions of acres of forestland around the world. Alien plant species have been introduced into non-native environments to provide food, feed, fiber, and timber, and as a result have disrupted local fauna and flora. Certain aspects of modern farming have had a negative impact on the biodiversity of crop plants and on air, soil, and water quality; nevertheless, it sustains and nurtures most of the world's six billion people with adequate nutrition and affordable food.

How can we address the potential environmental concerns of GM crops in the context of our experience with traditional crop variety deployment? We have continuously introduced genes for disease and pest resistance through conventional breeding into all of our crops. Traits, such as stress tolerance and herbicide resistance, have also been introduced in some crops, and the growth habits of every crop have been altered. The risk of crop gene flow to weedy relatives has always existed, and such "gene flow" occurs where possible. Thus, it is comforting to recognize that no major "superweeds" have developed since the advent of modern plant breeding, although there have been a few instances of crops ever becoming weedy or of weeds becoming more invasive due to gene transfer from crops. Most noxious weeds, such as kudzu, water hyacinth, and parthenium, resulted from the introduction of semidomesticated wild plants into non-native environments without the checks and balances of their native pests. Yet, there are probably no dwarf plants among the wild *Oryza* spp. and *Triticum* spp. populations in the Middle East or Asia, despite the fact that we now have been growing diminutive rice and wheat varieties for decades.

The risk of gene transfer to wild plants is exacerbated when crops are planted in an area with compatible weedy relatives (as often seen in their centers of origin), when such species are promiscuous outcrossers (canola), or, most importantly, when the introduced genes enhance the reproductive fitness of the recipient weeds (although most genes introduced into crop plants, conventional or biotech, have little value in the wild). The risk of gene transfer to weeds is similar with both conventional and GM crops and is not contingent on how we introduced these genes into plants. We must be vigilant to ensure that weeds do not become noxious as a result of any new crop variety. The current case-by-case testing and monitoring approach with biotech crops is a good regimen for the future, while the past experience with conventional crops provides assurance that such risks will be minimal and manageable.

Crop biodiversity is another issue of concern. The popularity of high-yielding varieties has already narrowed the genetic variation found in major crops. Biotechnology, if employed strategically, can reverse this through the recovery of older varieties that were discarded for lack of certain features (such as resistance to new disease strains), because modern gene transfer can restore such traits. Biotechnology research is also enabling the development of better methods for ex situ preservation of germplasm, such as cryopreservation, whereby valuable germplasm is being stored and thus saved from extinction.

The introduction of corn with a single transferred Bt gene has led to some concern about its ecological impact. While this concern should not be dismissed, it should be balanced with our hindsight and experience with corn itself, an introduced alien species now grown on 75 million acres in the United States, where none existed about 1,000 years ago. A crop introduced into a new environment entails the wholesale introduction of thousands of new genes. When grown on massive amounts of land, it exerts considerable ecological impact on the native fauna and flora, including beneficial insects. In contrast, the introduction of one or two genes into this background of 50,000 genes present in corn will have relatively less effect on the environment. While the initial fear about the reported damage to monarch butterflies from Bt corn has not held up in additional studies, one also needs to consider the negative impact of alternate practices (such as pesticide sprays) and recognize the potential for positive impacts on beneficial insects by the GM crop due to the specificity of the insect target(s).

For that matter, any concern about "gene pollution" pales in comparison to the massive "risk" of alien crop introduction, as 95% of the crop area in the United States now consists of such introduced crops. Concern about horizontal transfer of genes from GM crops to other organisms, such as bacteria, has also been expressed. But it appears highly unlikely that the risk is dependent upon the method of gene introduction. An inherent feature of biotechnology is that it lends itself easily to molecular detection of introduced genes, but a true measure of risk can only come in comparisons with classically bred crops where little or no such studies have been performed. Concerns such as random gene insertion, gene instability, and genomic disruption due to gene transfer have been expressed, but they are unlikely to be unique to GM crops or of any significance considering our current knowledge of genomic flux in plants. Worries about mixing genes from unrelated species ignore the history of plant breeding and the existing

overwhelming sequence similarity of genes across kingdoms. Nevertheless, scientific research aimed at risk analysis, prediction, and prevention, combined with adequate monitoring and stewardship, must continue so that negative ecological impact from GM crops will be kept to a minimum. Most problems raised by science can be solved by additional science itself. For example, appropriate promoters may ensure that pollen will not express genes toxic to beneficial insects, while gene expression strategies, such as sterile pollen, could reduce the risk of gene flow.

One must also recognize the potential positive impact of GM crops on the environment, such as decreasing agricultural expansion to preserve wild ecosystems; improving air, soil, and water quality by promoting reduced tillage, reducing chemical and fuel use; improving biodiversity through resuscitation of older varieties and promotion of beneficial insects; and cleaning up contaminated soil and air through phytoremediation.

As we chart ahead with more exciting developments in biotechnology, such as genomics, and grapple with issues arising from consumer acceptance of innovations, historical knowledge on societal adoption of technological innovations may provide some valuable perspectives to scientists. Many innovations that would be good candidates for generating consumer apprehension and concern today were introduced in the past without concern because the public was less informed about innovation. The precautionary principle was never invoked to ensure the scientific certainty that crop varieties developed using nuclear irradiation or chemical mutagens were safe. And food labeling was never demanded for bread wheat improved with the addition of hundreds of unknown goat grass genes.

Many other innovations that are now commonplace in our lives were met with skepticism and opposition when first introduced. Such fear of technology was especially more pronounced in food-related innovations (e.g. Pasteurization, canning, freezing, the microwave oven). However, once consumers recognize that new innovations can enhance their quality of life and once they understood that risks are either minimal or manageable, such technology eventually could enjoy public acceptance. This includes even those "disruptive" technologies that replace older ones (e.g. cars versus horse buggies, compact disc versus cassette tape). Nevertheless, there are historical instances of useful innovations that have not been readily accepted due to a variety of reasons, such as recalcitrance to adapt (e.g. Dvorak versus QWERTY keyboard), entrenched economic interests opposing change (e.g. the metric system in the United States; Beta versus VHS videotape), ideological opposition (e.g. plant breeding during Stalin-era Soviet Union by Lysenko), exaggerated notions of risk (e.g. food irradiation), ill-timed product introductions, and serious conflicts with societal values and beliefs.

Humans and crops will always be mutually dependent on each other's survival, and the guided evolution of crops will continue but increasingly will be more knowledge-based and responsible. An appreciation of the history of agricultural development however may provide us with a useful roadmap for devising appropriate strategies to informing and rationalizing societal responses to crop improvement. Paraphrasing the American philosopher George Santayana, ignoring history may condemn us to repeat it, but an understanding of the past may as well lead us to an enlightened future.

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