The Genetically Modified Crop Debate in the Context of Agricultural Evolution[1]

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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, Frankensteinlike, with the very stuff of life?"—Prince Charles (Windsor, 1998)

Throughout history, there have been those who have embraced change and those who have clung to the old ways because they felt that at least the risks were known. Few Edisons or Einsteins were properly recognized during their lifetime. And, since feeding ourselves has been the primary occupation of humankind for most of recorded and prerecorded histories, 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.

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Farmers have embraced biotechnology 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 approximately 110 million acres in thirteen countries. Ingredients produced from biotech crops are found in thousands of food products consumed worldwide. However, although no unequivocal evidence of harm to our health or the environment from these crops is known or expected, an intense debate is focused on their value and safety.

Societal anxiety over 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, negative opinion from the news media, opposition from 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 agriculture and food.

Two decades ago, many agricultural scientists rightfully saw the emerging recombinant DNA technology as a potent tool for enhancing crop productivity and food quality, while promoting sustainable agriculture. The early excitement and expectation was followed by successive breakthroughs in identification of valuable genes, development of gene-transfer methods, and the eventual production of transgenic crops. Breeders saw the technology as a complementary means of achieving crop improvement, and, for the first time, the products of their efforts were 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 of, and support for, biotechnology within the scientific community. Accumulated experience and knowledge of decades of crop improvement combined with expert judgment, science-based reasoning, and empirical research have given 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 be balanced against the enormous potential benefits from this technology and weighed against alternative options. The strong trust of the American public in its regulatory agencies (the Food and Drug Administration, the United Stated Department of Agriculture, and the Environmental Protection Agency) has fostered higher public acceptance of GM food in this country than elsewhere.

Mutant Food and Monarch Butterflies

Despite promised benefits, global negative reaction to GM crops ranges from mild unease to strong opposition. Typical questions include:

- Is it ethical for scientists to modify living organisms?
- Is it morally right to tamper with our food supply?
- Is genetic modification of crops inherently hazardous?
- Despite built-in safeguards, can we unwittingly make our foods unsafe?
- What about the long-term consequences of consuming foods containing GM ingredients?
- Do GM crops affect the environment or wild ecosystems, reducing crop biodiversity, beneficial insects, or the revered monarch butterfly?
- Could GM crops lead to the development of noxious "super-weeds"?
- Are we introducing GM crops into our environment without fully understanding the consequences of such action?
- Should we be concerned 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, given the complexities of these issues? Creating an awareness of agricultural history may provide a good beginning. 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."

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Crop Evolution and Human Civilization

Agriculture evolved independently in many places on this earth, but the earliest evidence of farming dates to 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 in the Middle East, the Andean region of South America, Mexico, and parts of Asia, and diffused throughout much of the globe. The change from a nomadic lifestyle to farming led us to become community dwellers, eventually spawning the development of languages, literature, and science and technology as people were freed from the daily task of finding food. These developments were more rapid in some regions than in others by thousands of years (Diamond, 1999). Plants evolved rapidly, or, more accurately, they were changed, as a result of human intervention (Harlan, 1992).

Every crop 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 species from the pool of a quarter of a million flowering plants before settling on the thousand or so that were subsequently “tamed” and adapted to farming. A little over a hundred species are now grown intensively around the world, of which only a handful supplies us with most of what we 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 phenotype occurred during such selection, including determinate growth habit; elimination of grain shattering; synchronous ripening; earlier maturity; reduction of bitterness and toxins; reduced seed dispersal, sprouting and dormancy; greater productivity, including larger 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 totally dependent upon human care for their survival, and modern varieties would persist in the wild “no longer than a Chihuahua would last in the company of wolves” (Trewavas, 2000).

Most of the crops that supply our food were first domesticated at the end of the Stone Age, often from a relatively narrow pool of 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 with corn (popcorn, sweet corn, dent corn, broom corn, and flour corn for tortilla and corn bread) and cabbage (kale, kohlrabi, Brussels sprouts, cabbage, cauliflower, and broccoli).

With the advent of transoceanic navigation and the “discovery” of the New World, crops were moved rapidly around the globe, and some achieved acceptance far beyond their natural centers of origin or domestication. For instance, the United States is the leading producer of corn and soybean in the world, yet these crops are native to Mexico and China, respectively. The world’s largest traded commodity, coffee, from its humble origins in Ethiopia now is grown 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 the United States other than the blueberry, Jerusalem artichoke, sunflower, and squash is borrowed from elsewhere!

A few sources of our food are recent domesticates. Careful breeding rendered palatable the Chinese gooseberry, native to China, and it was rechristened “kiwi fruit” after introduction to New Zealand early in the twentieth century. The modern strawberry with large fruits is a product of accidental crossing of two wild species from Virginia (United States) and Chile in France in the mid-eighteenth century. Rapeseed, grown in India for centuries, was altered recently through classical breeding to eliminate the toxic erucic acid and malodorous glucosinolates to result in canola. Triticale, a completely new crop, was artificially synthesized a century ago by combining the genomes of wheat and rye (from two 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

Farmers have molded the evolution of crop plants for several millennia, leading to rich diversity especially in traits related to their planting or consumption. At the same time, global population grew very slowly until the mid-nineteenth 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 5 billion people in 1987 to six billion in 1999. 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 has increased in every part of the world in the past few decades, including Africa. Per-capita food consumption has also increased steadily everywhere except in parts of sub-Saharan Africa. In the United States, where such scientific developments and their applications have been most intense, the average farmer now produces enough to feed nearly 150 people. In crops subject to intensive scientific attention—corn, soybean, wheat, and rice—the productivity levels have increased several fold. For example, American corn growers averaged 26 bushels/acre in 1928 and 134 bushels/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 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. When a crop variety refused to mate with the wild species, various tricks were employed to force intermingling, such as 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, neutrons), 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 is it likely that they are 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 several decades, plant breeders have radically transformed our crops by altering their architecture (*e.g.* dwarf wheat and rice), shortening the time to flowering, developing greater resistance to disease and pests (all crops), and developing larger seeds and fruits (Figs. 1 and 2). These

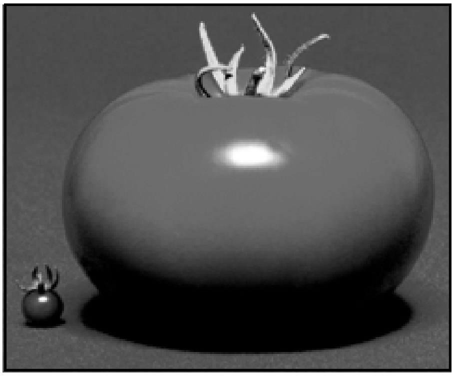

Figure 1. Wild *Lycopersicon pimpinellifolium* (left, diameter 1 cm) and a commercial tomato. (Kindly provided by Steve Tanksley.)

crops are also more responsive to management and are better adapted to diverse ecological conditions. Improved food quality has 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 one-thousand-fold increase in the volume of the marble-sized wild *Lycopersicon* has 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. The average American family spends only 11% of its income on food, and yet has access to better choices with more variety and nutrition than ever before. Without scientific developments in agriculture, we would be farming every square inch of arable land.

Figure 2. Wild teosinte (left), a modern corn hybrid (right), and their hybrid (center). (Kindly provided by John Doebley.)

Using gene-transfer techniques to develop GM crops is a logical extension of the continuum of devices we have used to improve crop plants for millennia. When compared to the gross genetic alterations associated with wild-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 also is clearly more expeditious, as the development of new cultivars by classical breeding typically takes from 10 to 15 years. The primary attraction of 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-species compatibility.

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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 more than a century of accumulated experience and knowledge with the latter. Although it may seem logical to express the concern, "I don't know what I am eating with GM foods!" it must be remembered that we have never had that information 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 encode toxins or allergens—armaments that wild plants deploy to survive. Yet we never routinely tested conventionally bred varieties for any 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.

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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 readily into our diets. What is more, we rarely, if ever, asked the same questions that we now pose about GM crops. Lately, many so-called functional foods, health foods, and nutraceuticals have entered the mainstream American diet with little or no regulation or testing. We do not question the long-term health implications of these food supplements, 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 oils, starches, and sugars, such proteins are not even present. 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 a 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 large proportions in our food, and we must be sensitized to them over time if they are to cause 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 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). Our food naturally contains thousands of chemicals, many of which are hazardous in laboratory-animal studies in huge doses. Our diet includes 5,000 to 10,000 natural toxins, which plants have evolved as protection against pests, diseases, and herbivores (Ames et al., 1990a). For instance, roasted coffee has over a thousand chemicals of which twenty-seven have been tested and nineteen found to be carcinogens in rodents (Ames and Gold, 1997). The fat-soluble neurotoxins solanine and chaconine, present in potato, 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 increases in such toxic compounds.

Thus, it is erroneous to assume that we never had problems with conventionally bred varieties. Although any variety found to pose a real health risk was promptly removed from the market, they were never routinely tested (in contrast to GM crops). One pest-resistant celery 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 as was the potato variety Lenape, which contained very high levels of solanine. With all innovations we learned by trial and error. Similarly, crop-improvement practices evolved over time with continued refinement. It is common, though, for human nature to generate an exaggerated fear of innovations while perceiving older or “natural” products as more benign. Huber (1983) discussed 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*, and *Salmonella*, 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 large numbers in Africa, contains cyanogenic glucosides that 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. If the current regulatory standards imposed on GM crops were to be invoked for traditional crops, many would fail to meet requirements.

Humans have built-in natural defenses for protection 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, our ancestors chose them intuitively 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 nutritional quality and is also being employed to reduce harmful toxic compounds that exist in our food.

Environmental Concerns

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 nonnative 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 the quality of air, soil, and water; nevertheless, it sustains and nurtures most of the world's six billion people with adequate nutrition and affordable food.

How can we address the environmental questions concerning GM crops in the context of our experience with traditional crop-variety deployment? Through conventional breeding, we have continuously introduced genes for resistance to diseases and pests into all of our crops. Traits, such as stress tolerance and herbicide resistance, have also been introduced in many crops, and the growth habits of every crop have been altered. The risk of crop "gene flow" to weedy relatives has always existed. 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 becoming weedy or of weeds becoming more invasive due to gene transfer from crops. Most noxious weeds, such as kudzu (*Pueraria lobata*), water hyacinth (*Eichhornia crassipes*), and parthenium weed (*Parthenium hysterophorus*) resulted from the introduction of whole genomes of exotic semi-domesticated wild species without the checks and balances of their native pests. Yet, there are probably no dwarf plants among the wild *Oryza* and *Triticum* populations in Asia and the Middle East, despite the fact that we have been growing diminutive rice and wheat varieties for decades.

The risk of gene transfer to wild species is exacerbated when crops are planted in an area with compatible weedy relatives (as often seen at their centers of origin), when such species are promiscuous out-crossers (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 conventional and GM crops and is not contingent upon how the genes are introduced to the crop. 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 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 concern about its ecological impact. While this concern should not be dismissed, it should be balanced with hindsight and experience. Corn is an introduced alien species grown on 75 million acres in the United States, where none existed a thousand years ago. A crop grown in a new environment entails the wholesale introduction of thousands of new genes. When cultivated on huge areas 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 the tens of thousands of genes present in corn will have relatively less effect on the environment. Whereas 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 spraying) and recognize the potential for positive impacts on beneficial insects by the GM crop due to its specificity regarding targeted insects.

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, also has been expressed. But it appears highly unlikely that any such 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 over random gene insertion, gene instability, and genomic disruption due to gene transfer are unlikely to be unique to GM crops or of any significance considering our

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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, and reducing chemical and fuel use; improving biodiversity through resuscitation of older varieties; 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 has been especially pronounced in food-related innovations (*e.g.* pasteurization, canning, freezing, the microwave oven). However, once consumers recognized that these innovations enhanced the quality of life and once they understood that risks are either minimal or manageable, then these technologies enjoyed public acceptance. This includes even "disruptive" technologies that replaced older ones (*e.g.* automobile vs. horse buggy, compact disc vs. 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 *vs*. 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 by Lysenko during Stalin's rule of the Soviet Union), exaggerated notions of risk (*e.g.* food irradiation), ill-timed product introductions, and serious conflicts with societal values and beliefs.

The survival of humans and crops will always be mutually dependent, and the guided evolution of crops will be increasingly knowledge-based. 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. On the other hand, an understanding of the past may well lead us to an enlightened future.

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