From the dawn of civilization, mankind has been modifying plants at the genetic level to suit its needs, and the fates of human society and agricultural crops have been inextricably linked and mutually interdependent ever since. Agriculture allowed humans to abandon hunter-gatherer behavior, in turn spawning broader economic and cultural development. And the suitability of certain plant species for food or fiber—which provided the proximate cause for their eventual domestication—let those organisms survive and thrive far beyond their original ranges.

Our ancestors chose a few once-wild plants and gradually modified them simply by selecting those with the largest, tastiest or most robust offspring for propagation. In that way, organisms have been altered so greatly over the millennia that traits present in existing populations of cultivated rice, wheat, corn, soy, potatoes, tomatoes and many others have very little in common with their ancestors. Wild tomatoes and potatoes contain very potent toxins, for example. But today's cultivated varieties have been modified to produce healthy and nutritious food.

Breeding safe and useful crops from wild plants was a remarkable feat, given how poorly those first plant breeders understood the dynamics of selection and heritability. It was not until the 19th century that plant genetic modification became anything other than a hit or miss affair. Gregor Mendel's discovery of the principles of inheritance in the 1860s gave rise to a revolution in crop hybridization, perhaps best characterized by the life of horticulturalist Luther Burbank. Burbank developed more than 800 new varieties of fruits, vegetables, flowers, and trees—some so unique that he was eventually awarded patents on 16 of his plants.

Yet, despite the predictive capacity that arose from Mendelian principles, actual understanding of the source of plant characteristics was still quite limited until the turn of the 20th century. Verification of Mendel's principles initiated a wave of new genetic discoveries clarifying how nucleic acids within plant cells controlled the generation of specific traits. From that point forward, hybridization could truly be considered more a science than an art.

Early experiments in corn hybridization by G.H. Shull in the 1900s established the modern genetics foundation for a revolution in food and fiber production. Shull's scientifically guided corn breeding helped lay the groundwork for the Green Revolution some half a century later, and initiated yield growth from fewer than 30 bushels per acre in the 1920s to more than 130 bushels per acre in the late 1990s. Such productivity gains helped North American and European farmers grow more food at a lower cost, without having to encroach upon forests and other wildlands to feed an ever-growing population. Crop improvement has thus been one of the most important environmental success stories in history.

Modern genetics has been so powerful an influence on food production that, in a recent survey, members of the North American Agricultural Journalists professional society ranked crop hybridization, recombinant DNA genetic modification, discovery of DNA's double helix structure and the Green Revolution as the four most important developments in agriculture during the past 50 years.

The productivity gains derived from scientifically bred, high yielding crop varieties allowed the world's farmers to double output during the last 50 years, on roughly the same amount of land, at a time when global population rose more than 80 percent. Without genetics and other scientific developments in agriculture, we would today be farming on every square inch of arable land to produce the same amount of food, destroying hundreds of millions of hectares of pristine wilderness in the process.

How natural are our crops?

All crops are unnatural. Not only are they vastly different from their wild ancestors, but most also had their origin and domestication far from where they are now grown. For instance, the US is the world's leading producer of corn and soy, yet these crops are native to Mexico and China, respectively. Wheat, grown throughout Western Europe, was domesticated in Mesopotamia. The

world's largest traded commodity, coffee, had a humble origin in Ethiopia. But now, most coffee is produced in Latin America and Asia.
Florida oranges have their roots in India, while sugarcane arose in Papua New Guinea. Food crops that today are 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 is borrowed from somewhere else.

All our crops, domesticated long ago, have more recently been improved for human use. Rapeseed, grown in Asia for centuries, naturally contains two dangerous chemicals that make it more amenable for use as a lubricant than a cooking oil. But in the 1960s, Canadian scientists used conventional breeding techniques to eliminate the genes responsible for producing those toxic and smelly chemicals. They named their creation canola (short for Canadian oil), a popular but completely new crop now grown widely in North America and Europe.

In the most fundamental sense, all plant and animal breeding involves, and always has involved, this kind of intentional genetic modification—adding useful new genes and shedding old deleterious ones. And though critics of today's most advanced breeding method, recombinant DNA, believe it is somehow unique, there have always been Cassandras to claim that the latest technology was unnatural, different from its predecessors and inherently dangerous. As early as 1906, Luther Burbank noted that, "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 the utmost caution in the application of this new found knowledge," a cautionary note one might just as easily hear today regarding recombinant DNA—modern genetic modification.
But just as Burbank was wrong to claim that there was some special danger in the knowledge that permitted broader sexual crosses, so are today's skeptics wrong to believe that modern genetic modification poses some inherently greater risk. It is not genetic modification per se that generates risk. Recombinant DNA modified, conventionally modified and unmodified plants could all prove to be invasive, harmful to biodiversity or harmful to eat. Rather, risk arises from the characteristics of individual organisms, as well as how and where they are used. Thus, an understanding of the historical context of genetic modification in agriculture may help us to better appreciate the potential role of recombinant DNA technology, and quell public anxieties about its use.

Even though it is guided by human hands, hybridization may seem perfectly natural when it simply assimilates desirable traits from several varieties of the same species into elite cultivars. But when desired characteristics are unavailable in cultivated plants, hybridization can be used to borrow liberally from wild and sometimes quite distant relatives. Domesticated tomato plants are commonly bred with wild tomatoes of a different species to introduce improved resistance to pathogens, nematodes and fungi. Successive generations then have to be carefully back-crossed into the commercial cultivars to eliminate any unwanted traits accidentally transferred from the wild varieties, such as glyco-alkaloid toxins common in the wild species.

When crop and wild varieties do not readily mate, various tricks can be employed to produce so-called "wide crosses" between two plants that are otherwise sexually incompatible. Still, the embryos created by wide crosses usually die prior to maturation, so they must be "rescued" and cultured in a laboratory. Even then, the rescued embryos typically produce sterile offspring. They can only be made fertile again by using mutagenic chemicals that cause the plants to produce a duplicate set of chromosomes. The plant triticale, an artificial hybrid of wheat and rye, is one such example of a wide-cross hybrid made possible solely by the existence of embryo rescue and chromosome doubling techniques. Triticale is now grown on more than three million acres worldwide, and dozens of other wide-cross hybrids are also common.

Finally, when a desired trait cannot be found within the existing gene pool, breeders can create new variants by intentionally mutating plants with x-ray or gamma radiation, with mutagenic chemicals or simply by culturing clumps of cells in a petri dish. A relatively new mutant wheat variety has been produced with chemical mutation to be resistant to the BASF herbicide ClearField. Mutation breeding has been in common use since the 1950s, and more than 2,250 known mutant varieties have been bred in at least 50 countries, including France, Germany, Italy, the UK and the US.

It is important to note that these sophisticated and unnatural breeding techniques are considered "conventional," and go almost totally unregulated. Yet, despite the massive genetic changes and potential for harm, consumers and anti-technology activists are largely unaware of their existence and evince no concern.

Along comes recombinant DNA

As we have seen, all modern crops are a product of various genetic meddling. Recombinant DNA methods can therefore be seen as an extension of the continuum of techniques used to modify organisms over the millennia. The biggest difference is that modern genetically modified crops involve a precise transfer of one or two known genes into plant DNA—a surgical alteration of the crop's genome compared to the sledgehammer approaches of traditional hybridization or mutagenesis. Furthermore, unlike varieties developed from more conventional breeding, modern genetically modified crops are rigorously tested and subject to intense regulatory scrutiny prior to commercialization.

There has been widespread acceptance and support for recombinant DNA modification from the scientific community, plant breeders and farmers. Accumulated experience and knowledge of decades of crop improvement combined with expert judgment, science-based reasoning and empirical research has generated confidence that modern genetically modified crops will pose no new or heightened risks that can not be identified and mitigated, and that any unforeseen hazards are likely to be negligible and manageable.

Many growers have embraced modern genetically modified technology because it makes farming 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 with recombinant DNA technology are now grown on nearly 58 million hectares in 16 countries. More importantly, more than three-quarters of the 5.5 million growers who benefit from genetically modified crops are resource-poor farmers in the developing world.

High anxiety?

Ingredients produced from modern genetic modification are found in thousands of food products consumed worldwide. Yet, even though no legitimate evidence of harm to human health or the environment from these foods is known or expected, there is an intense debate questioning the value and safety of genetically modified organisms.

Although it may seem reasonable for consumers to express a concern that they "don't know what they're eating with genetically modified foods," it must be repeated that consumers never had that information with conventionally modified crops either. Indeed, while no assurance of perfect safety can be made, breeders know far more about the genetic makeup, product characteristics and safety of every modern genetically modified crop than those of any conventional variety ever marketed. Breeders know exactly what new genetic material has been introduced. They can identify where the transferred genes have been inserted into the new plant. They can test to ensure that transferred genes are working properly and that the nutritional elements of the food have been unchanged. None of these safety assurances can be made with conventional breeding techniques.

Consider, for example, how conventional plant breeders would develop a disease-resistant tomato. Sexual reproduction introduces chromosome fragments from a wild relative to transfer a gene for disease resistance into cultivated varieties. In the process, hundreds of unknown and unwanted genes are also introduced, with the risk that some of them could encode toxins or allergens. Yet regulators never routinely test conventionally bred plant varieties for food safety or environmental risk factors, and they are subject to practically no government oversight.

We have always lived with food risks. But modern genetic technology makes it increasingly easier to reduce those risks.

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 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 biodiversity and on air, soil and water quality. But do modern genetically modified crops really pose even greater environmental risks, as critics claim?
The risk of cross-pollination from crops to wild relatives has always existed, and such "gene flow" occurs whenever crops grow in close proximity to sexually compatible wild relatives. Yet breeders 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 with conventional techniques, and the growth habits of every crop have been altered. Thus, not only is gene modification a common phenomenon, but so are many of the specific kinds of changes made with recombinant DNA techniques.

Naturally, with both conventional and recombinant DNA-enhanced breeding, we must be vigilant to ensure that newly introduced plants do not become invasive and that weeds do not become noxious as a result of genetic modification. Although modern genetic modification expands the range of new traits that can be added to crop plants, it also ensures that more will be known about those traits and that the behavior of the modified plants will be, in many ways, easier to predict. That greater knowledge, combined with historical experience with conventional genetic modification, provides considerable assurance that such risks will be minimal and manageable.

It should also be comforting to recognize that no major weed or invasiveness problems have developed since the advent of modern plant breeding, because domesticated plants are typically poorly fit for survival in the wild. Indeed, concerns about genetically modified crops running amok, or errant genes flowing into wild species—sometimes characterized as "gene pollution"—pale in comparison to the genuine risk posed by introducing totally unmodified "exotic" plants into new ecosystems. Notable examples of the latter include water hyacinth in Lake Victoria, cord-grass in China, cattail in Nigeria and kudzu in North America.

This is, of course, not to say that no harm could ever come from the introduction of modern genetically modified or conventionally modified crop varieties. Some traits, if transferred from crops to wild relatives, could increase the reproductive fitness of weeds and cause them to become invasive or to erode the genetic diversity of native flora. But the magnitude of that risk has solely to do with the traits involved, the plants into which they are transferred and the environment into which they are introduced. Consequently, breeders, farmers and regulators are aware of the possibility that certain traits introduced into any new crop varieties, or new varieties introduced into different ecosystems, could pose genuine problems, and these practices are carefully scrutinized. Again, though, this risk occurs regardless of the breeding method used to introduce those traits into the crop.
Finally, one must also recognize the potential positive impact of recombinant DNA modified crops on the environment. Already, commercialized genetically modified crops have reduced agricultural expansion and promoted ecosystem preservation, improved air, soil and water quality as a consequence of reduced tillage, chemical spraying and fuel use and enhanced biodiversity because of lower insecticide use.

Studies have shown that the eight most common modern genetically modified crops grown in the US alone increased crop yields by nearly 2 billion kilograms, provided a net value of US$1.5 billion and reduced pesticide use by 20 million kilograms. A 2002 Council for Agricultural Science and Technology report also found that recombinant DNA modified crops promote the adoption of conservation tillage practices, resulting in many other important environmental benefits: 37 million tons of topsoil preserved, 85 percent reduction in greenhouse gas emissions from farm machinery, 70 percent reduction in herbicide runoff, 90 percent decrease in soil erosion and from 15 to 26 liters of fuel saved per acre.

Conclusion: Societal anxiety over the new genetic modification is, in some ways, understandable. It is fueled by a variety of causes, including unfamiliarity, lack of reliable information about regulatory safeguards, 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.

Humans and crops will always be mutually dependent upon one another's survival, and the guided evolution of crops will continue but increasingly will be more precise and safer. An appreciation of the history of agricultural development, however, may provide us with a useful roadmap for devising appropriate strategies for informing the public and making rational societal responses to crop improvement.