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TOMORROW'S TABLE

Organic Farming, Genetics, and the Future of Food

PAMELA C. RONALD & RAOUL W. ADAMCHAK

Second Edition

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Perhaps, like oil and water, science and politics do not mix—or so I wonder as I gaze out the window of my friend Beth's Toyota Camry as she steers us along the winding roads of the Sonoma Valley wine country. We are on the way to our annual yoga retreat, and the rolling hills provide a refreshing contrast to the flatness of the Central Valley, where we both live. The sun shines through gaps in the rain clouds, illuminating the brilliant fall foliage of the vineyards. The pumpkins balanced on the farmers' fence posts look as if they have been immersed in a dye extracted from the turning leaves. We pass a Victorian farmhouse set back from the road. In the tidy yard, a sign proclaims: "Yes on Proposition M." If passed, the 2005 initiative, Measure M, "would, for at least the next 10 years, prohibit the raising, growing, propagation, cultivation, sale, or distribution of most genetically engineered organisms in Sonoma County."[1]

I hope that voters know that the beauty here is threatened by a tiny bacterium called *Xylella fastidiosa* that causes a disease lethal to the vines. It is transmitted by an insect called the glassy-winged sharpshooter. As the insect sucks the nutritious liquids out of the grape leaf veins, it injects the bacterium, which then multiplies, spreads, and clogs the veins that supply the plant with water. The result is mottled leaves on plants that take several years to die. During severe epidemics, a vineyard will look as if it had been scorched by a fast moving fire. At this point, destruction of vines and replanting are the only way to save an infected vineyard. The county's 60,000 acres of wine grapes, with an annual value of more than $300 million, are at risk. Certain grape varieties, including Barbera, Chardonnay, and Pinot Noir, are susceptible to this disease. Because there are few known varieties with resistance, standard breeding for resistance is limited.[2] Pesticides, even the most toxic, do little to deter the insect. Scientists are trying to genetically engineer the grape vines using a method similar to that successfully used to protect the papaya from the ringspot virus[3] (see Box 4.3 in Chapter 4). If passed, the proposed ban on genetic engineering would prevent future planting of genetically engineered grapes that are resistant to *Xylella*.

Beth, the long-time manager of the local food co-op that buys from many organic farmers in the area, tells me that several organic trade associations, including the California Certified Organic Farmers, support Measure M. The Sonoma initiative has carved out exceptions that allow for buying, selling, and consumption of medicine and food with genetically engineered ingredients. For example, patients who use genetically engineered insulin can still take their medicine. Consumers can still buy, sell, and eat cheeses made with genetically engineered rennet (Box 5.1). Beth asks, "If people are not worried about genetically engineered cheeses or medicines, why are they so worried about crops?"

BOX 5.1 **Genetically Engineered Rennet**

Cheese is made by coagulating milk with the addition of rennet to produce curds. The curds are separated from the liquid whey and then processed and matured to produce a wide variety of cheeses. The active ingredient of rennet is the enzyme chymosin. Until 1990, most rennet was produced from the stomachs of slaughtered newborn calves. Today, at a 10th of the 1990 cost, chymosin is produced through genetic engineering. Genetically engineered chymosin is distributed globally, with 80% to 90% of the hard cheeses in the United States and United Kingdom produced using genetically engineered chymosin.[4–6]

I reply, "I think some consumers feel that crops developed through genetic engineering are more harmful than seed developed through conventional breeding. They may not realize that these crops are safe to eat."

Another concern is that the genetically engineered corn grown here is sold by the Monsanto Corporation. Although not mentioned in the initiative, the dominance of this large seed company is a major issue for some consumers and may be the underlying reason for the proposed ban. Many consumers have not forgotten that Dow Chemical and Monsanto were the two largest producers of Agent Orange for the US military during the Vietnam War.

"Also, many people are suspicious of large seed companies—especially Monsanto," I add. "They see Monsanto as evil."

Beth says, “You are right; people hate Monsanto. Few people are willing to trust the maker of Agent Orange to genetically engineer their food.”

“Do you think if people knew that genetic engineering is being used by non-profit organizations to boost nutrients in foods for malnourished children there would still be so much protest against the technology?” I ask.

“Probably not,” Beth says.

“People might want to get rid of Monsanto but this initiative won’t do the job, ” I say. “Monsanto will still sells other kinds of seeds to farmers. Even organic farmers buy much of their seed from Monsanto.” [7–10]

Another part of the opposition is the misconception that planting genetically engineered seed prevents farmers from integrating other approaches to controlling pests and disease that foster a healthy farm system. Genetically engineered seed is not a magic bullet that will solve all agricultural problems. Seed is just one component of agriculture; ecologically based farming practices are another. Farmers need both.

Beth and I further contemplate the motives behind the initiative. We know that in addition to perceived external manipulation of their food by multinational biotech companies, some consumers question the safety of the process of genetic engineering and worry that crops developed through this process will harm human health or the environment. They may also fear that organic growers will be decertified if pollen from genetically engineered crops cross-pollinates with organically grown crops. However, in the more than 20 years since genetically engineered crops have been on the market, no organic grower has been decertified for this reason. Decertification would be contrary to the standards set by the US Department of Agriculture (USDA). Testing for transgenes (e.g. a gene encoding a bacterial BT gene) is neither required nor encouraged by the USDA National Organic Program.[11]

Like all farmers, organic growers have pests that are difficult to control, but they have fewer tools available. For example, in the Central Valley, organic sweet corn does not rank as one of the top 20 organic crops sold because it is difficult to control the corn earworm pest in late summer. In the past, conventional farmers controlled this pest by spraying broad-spectrum insecticides (up to 15 times each summer). Today, some conventional farms plant Bt sweet corn that confers robust resistance to the corn earworm (Fig. 5.1).[12] Because Bt corn was generated through genetic engineering, organic farmers are prohibited from using this approach.

Instead, organic farmers try to reduce infestation by spraying the Bt pesticide (i.e., the same protein used in genetic engineering). However, this approach

FIGURE 5.1 Sweet corn infected with corn earworm. Left, Three ears of late-season organically grown sweet corn. Right, Three ears of Bt sweet corn developed through genetic engineering. (Courtesy of F. Gould, North Carolina State University, 2005.)

is expensive, and the sprays cannot reach inside the corn where the worm is feeding. Because there are few alternatives, organic growers accept wormy corn and hope their clientele does not mind. The Sustainable Agriculture Research and Education Foundation reports that organic growers are forced to offer one of their most profitable summer crops complete with extra, unwanted protein. "When the earworm hit, sales would drop considerably," said Steve Mong, a vegetable grower in Stow, Massachusetts, who has a roadside stand. "We would leave a knife on the table so anyone who didn't want to take a worm home with them could cut it out."[13]

Because the USDA National Organic Program standards prohibit planting genetically engineered crops, organic farmers do not directly benefit financially from the genetically engineered crops on the market. However, organic farmers benefit indirectly in two ways. First, the reduced application of chemical insecticides by their neighbors means there is less chemical drift onto the organic farms. The USDA reports a 10-fold reduction in sprayed insecticide on corn over the past 15 years due to planting of Bt corn,[14,15] Second, organic farmers benefit from fewer European corn borer infestations in their own fields. In 2010, researchers reported that the economic benefits of Bt corn accrue to farmers planting Bt corn and those planting non-Bt corn because when the insects deposit eggs in cornfields, the larvae die.[16] Bt cornfields become an effective dead-end trap crop for European corn borers. Cumulative benefits for Bt corn growers in Illinois, Minnesota, and Wisconsin over 14 years were estimated at $3.2 billion. More than $2.4 billion of this total accrued to non-Bt corn growers.[16]

Despite the stance of the organic trade organizations, some individual organic farmers would like more specific information about genetic engineering before they reject the technology outright. Our friend Frances is an organic farmer in the Central Valley community. She earned a history degree from Duke University and worked for Morgan Stanley in New York City before moving west in 1986. She worked at the famed Chez Panisse and Café Fanny restaurants in Berkeley, California, and in 1993, she founded a 70-acre organic farm with her husband. Their farm grows an array of fruits and vegetables, including rosemary, lavender, parsley, cherries, heirloom tomatoes, and nuts.

Frances has been following the debate on the use of genetic engineering off and on for many years. A few years ago, she said, "I am more confused than ever about genetic engineering. I have heard things that bother me, but then they turn out to not be true. I think people are making conclusions when they don't have the facts. They are trying to make the issue black and white when it is gray. It does not need to be one side against another, all good or all bad. I have also heard that farmers growing Bt crops use fewer insecticides. If this is true, how can I not feel like that is a good thing?"

Beth and I drive on. Next to a small barn converted into a winery, we see a gas station. We pull in and get out of the car to stretch. Beth notices a local flyer asking voters to support Measure M. It pictures the destruction in New Orleans wrought by Hurricane Katrina and the bewildered gaze of US President George W. Bush. The flyer proclaims, "Who do you trust with your family's health and safety? When the Federal Emergency Management Agency failed, more than a million Americans suffered." It strikes us both that the publicity is off the point, aimed more at frightening consumers than helping voters understand the issues. The government's response to the flooding of New Orleans has nothing to do with genetically engineered foods.

However, as my friend Sarah Hake, a corn geneticist at UC Berkeley says, "Fear sells; data do not. The successes of genetic engineering are seldom described in the popular press—rather, we are given a smorgasbord of reasons to be afraid. Supporting anti–genetically engineered measures shuts the door to important questions about the environmental and food safety consequences of growing genetically engineered crops."[14]

As we climb back in the car, Beth says, "Some of my customers are afraid of eating food that contains even minute amounts of ingredients that are from genetically engineered crops. They see the process of genetic engineering as unnatural. It just doesn't fit with their concept of farming. But then when I talk to farmers, they are curious about the possibilities even if they don't necessarily embrace the concept."

Her comments ring true. Based on Sonoma County, the rural-urban divide is evident. The Sonoma County Farm Bureau opposes Measure M. In contrast, urban residents, food processing companies, and wineries support it, hopeful to include "GMO-free Sonoma" on their label as a new way to market their products. It seems that the images of a farmer working the land, the cows chewing their grass, and the ripening fruit ready for the harvest represents the sort of life that many long for, a life of order and beauty that is free from pests, stress, and new technologies. Although this may be what people want, it is not the life most farmers or consumers lead.

We see this division elsewhere in California, with agricultural counties opposing additional restrictions on the use of genetically engineered crops and other counties favoring them. For example, in 2005, the board of supervisors in Kern County, California, the fourth largest agricultural county in the nation, passed a resolution affirming "the right for farmers and ranchers to choose to utilize the widest range of technologies available to produce a safe, healthy, abundant, and affordable food supply and that the safe, federally regulated use of biotechnology is a promising component of progressive agricultural production." Similar resolutions were passed by several other counties in the agriculturally rich San Joaquin Valley, including Fresno County, the largest agricultural county in the nation with more than $6.5 billion in annual agricultural income in 2012.[18]

Only voters in the California counties of Marin and Mendocino, which have fewer farmers, have passed anti–genetically engineered initiatives similar to Measure M. In 2012, Marin ranked 38 among California's 58 counties in terms of total value of agricultural products sold.[19] Mendocino sells even fewer products. The anti–genetic engineering laws that were subsequently enacted do not affect current crop production practices in those counties because there were no genetically engineered crops grown in the first place. Sarah and her husband, Don Murch, an organic farmer in Marin County, opposed the Marin Measure because as Sarah said, "Genetically engineered crops can be designed with built-in resistance to pests and disease, thereby reducing the use of pesticides or fungicides. This could make a difference in other counties where extensive pesticides are used."[20]

An hour later, Beth and I arrive at the retreat in Mendocino County. We say hello to our friends, unpack our sleeping bags and yoga mats, and pull out our groceries. In the kitchen, I sauté eggplants I brought from the student farm with chili, garlic, and olive oil (Recipe 5.1). We sit down to eat lunch and drink Chardonnay.

It turned out that Sonoma's Measure M was defeated. In 2004, three similar measures in Butte, San Luis Obispo, and Humboldt Counties were also rejected.[21] For many farmers, the issues were twofold: they did not want the government to regulate what they can grow, and they wanted to preserve the possibility of using genetically engineered crops to combat diseases such as the one in grapes caused by *Xylella*.

It seems that the initiative was more an act of defiance, a fight against the change that is ever constant in our lives, rather than a specific, constructive proposal to make agriculture in the county more ecological. In 2016, after a comprehensive review of the scientific literature, the National Academy of Science and Engineering reaffirmed numerous earlier studies that there is "no substantiated evidence that foods from genetically engineered crops are less safe than foods from non–genetically engineered crops."[22] Despite the new report, some Sonoma locals collected signatures to place a measure on the November 2016 ballot that would prohibit the planting of genetically engineered crops in the county. The group said the scientific findings would not affect their campaign.[23]

RECIPE 5.1

Spicy Eggplant

Ingredients

2 eggplants, diced into ½-inch cubes
3 Tbsp. of olive oil
1 clove of garlic, smashed and chopped
½ tsp. of chili flakes

1. Sauté smashed and chopped clove of garlic in the olive oil.
2. Add the chili flakes to the pan.
3. Add the eggplant to the pan; sauté until the eggplant is soft and tender.
4. Add salt to taste.

A few weeks after the yoga retreat weekend, my family has gathered for the Christmas holiday at Lake Tahoe. I am in the kitchen dicing Raoul's organically grown broccoli, while Anne, my sister-in-law, makes cornbread (Recipe 5.2). Anne lives in Marin County and voted in favor of an anti-GE ordinance in the November 2004 election. The ordinance was opposed by the Marin County Farm Bureau and the American Society of Plant Biologists, a nonprofit professional association, of which I am a member. The ordinance was passed, and now the county deems it unlawful to cultivate, propagate, raise or grow genetically engineered organisms.

It has been raining for 10 days, which means no playing in the snow, so we have plenty of time to talk. The ban is on my mind, so I ask Anne why she supports it. In many ways, Anne is a typical resident of Marin. She is educated, tries to make food choices that will support ecologically sound farming, is politically progressive, and spent many years as the president and member of the board of a nonprofit organization dedicated to safeguarding the environment in the Lake Tahoe Basin. Anne is concerned about genetic engineering, reads the news, and is willing to talk about it. She does not trust the scientific consensus on the safety of genetically engineered crops and thinks the crops were deployed too quickly. "I voted for the ordinance because it will send a message to the large corporations that the onus is on them to prove their products are safe for human consumption and the environment," she tells me.

I point out that the ordinance contained no language concerning the role of corporations but that it bans farmers from growing genetically engineered crops. I mention, too, that the National Academy of Science, the European Food Safety Authority, the World Health Organization, and every other major scientific organization has indicated that the crops currently on the market are safe to eat.[24–31]

"Even if they are safe to eat, I don't like the idea that many of the genetically engineered crops grown in the United States are sprayed with herbicides," she adds.

She is referring to one type of genetically engineered crop that is engineered with a bacterial protein that makes them tolerant of the herbicide glyphosate (i.e., herbicide tolerant). Glyphosate is the main component of Monsanto's Roundup and other generic versions of the same herbicide (see Box 2.2 in Chapter 2 and Box 5.2). Conventional farmers grow herbicide-tolerant crops because the herbicide spray kills weeds but not the herbicide-tolerant crop, and no additional weeding is needed. In 2017, herbicide-tolerant soybean comprised 94% of all acres planted in soybeans, and herbicide-tolerant corn was grown on 89% of all acres dedicated to corn.[14]

BOX 5.2 **Herbicide-Tolerant Crops**

Definitions and Use

Glyphosate-based herbicides (e.g., Roundup) commonly used by farmers and home gardeners, block a chloroplast enzyme (i.e., 5-enolpyruvoyl-shikimate-3-phosphate synthetase [EPSPS]) that is required for plant growth. When sprayed on leaves, these herbicides kill the entire plant in 2 weeks.

Crop plants genetically engineered for tolerance to glyphosate contain a gene isolated from *Agrobacterium* encoding an EPSPS protein that is tolerant to glyphosate. US farmers used herbicide-tolerant soybeans on 94% of all planted soybean acres in 2017.[14] Herbicide-tolerant corn accounted for 89% of corn acreage in 2017, and herbicide-tolerant cotton constituted 89% of cotton acreage.[14]

Adoption of herbicide-tolerant crops has a mixed impact on overall herbicide applications. Herbicide applications on soybean and corn declined in the first years after introduction of herbicide-tolerant seeds in 1996, but their use has increased slightly or moderately in recent years. Importantly, the types of herbicides that are applied have changed since the introduction of herbicide-tolerant crops. In soybeans and cotton, most other herbicides were replaced by glyphosate, which persists for a shorter time in the environment than the herbicides it replaced.[32] For example, before the advent of herbicide-tolerant soybeans, conventional growers applied the herbicide metolachlor to control weeds; it is a known groundwater contaminant.[33] Switching from metolachlor to glyphosate in soybean production has conferred environmental benefits because it reduced groundwater contamination (see Box 2.2 in Chapter 2).

In addition to a reduction in the use of more toxic herbicides, planting of herbicide-tolerant crops correlates with an increase in low-till and no-till agriculture, which leaves the fertile topsoil intact and protects it from being removed by wind or rain.[15,22,34,35] Because tractor tilling is minimized, less fuel is consumed, and greenhouse gas emissions are reduced.[34]

Rachel Long, a UC Cooperative Extension Adviser in Yolo County and a member of the Organic Farming Research Workgroup, reported that conventional alfalfa farmers in the Central Valley typically use Diuron and Paraquat to control weeds (Box 2.2). She said, "I am hoping that the new genetically engineered herbicide-tolerant alfalfa variety developed by Monsanto will help improve water quality in the valley."

Jim Anderson, Professor of Wheat Breeding and Genetics at the University of Minnesota, described two other benefits of glyphosate application: First, because glyphosate degrades almost immediately, there are no issues with sowing another crop after Roundup application. In contrast, many other herbicides persist in the soil, complicating planting of subsequent crops. Second, before the availability of glyphosate-based herbicides, weeds were controlled by chemical that did not work as well. Farmers have cited ease of use and quality of life as a reason to use herbicide-tolerant crops, which save them time and hassles.

Although herbicide-tolerant crops provide advantages for conventional growers and the environment, they do not directly benefit organic farmers, who are prohibited from using herbicides, or poor farmers in developing countries, who often cannot afford them.

The popularity of herbicide-tolerant crops and glyphosate has led to overuse and spurred the evolution of herbicide-resistant weeds.[36] Twenty-four glyphosate-resistant weed species have been identified since herbicide-tolerant crops were introduced in 1996.[36] Studies highlight the fact that application of glyphosate or other herbicides can be sustainable only if there is sufficient diversity of weed management practices.[37] Rather than applying a single herbicide repetitively over large areas, agronomists and weed-control specialists advocate an integrated pest management strategy to mitigate rate of development of resistance to a single herbicide.[22,38,39]

The evolution of weeds resistant to herbicides is a problem for farmers who rely on a single herbicide, regardless of whether they plant genetically engineered crops or not. For example, 64 weed species are resistant to the much more toxic herbicide atrazine, and no crops have been genetically engineered to withstand it. Even in the absence of herbicide-tolerant plants, conventional farmers need to develop strategies to manage weeds to minimize the evolution of resistance.

Health and Safety

Because of its widespread use of glyphosate, the potential health effects have been scrutinized by scientists and nongovernmental organizations. The US Environmental Protection Agency and the European Food Safety Authority have stated that glyphosate is practically nontoxic to humans, birds, fish, and honeybees. Glyphosate has approximately the same toxicity to mammals as does Dipel, a pesticide sprayed by organic farmers (see Box 2.2 in Chapter 2). Glyphosate is typically used in the early stages of growing crops such as soybeans, corn, and canola. Those crops, if they reach human consumers at all, are heavily processed first, destroying most of the glyphosate residues.[40] In 2015, the World Health Organization's International Agency for Research on Cancer announced that they would add glyphosate to their list of agents that were "probably carcinogenic for humans." This statement was evaluated by many scientists and journalists.[41–43] For example, Dan Charles, a reporter for NPR,[40] noted that "IARC is saying that glyphosate probably could cause cancer in humans but not that it probably does . . . other things that the IARC says probably cause cancer are burning wood in home fireplaces, disruption of circadian rhythms by working overnight shifts, and working as a hairdresser . . . the IARC report should remind people that 'they should be careful and thoughtful about how they use these chemicals' because some of their biological effects remain uncertain. The risks, whatever they may be, mainly affect the people who work with them or who come in direct contact with areas where they are applied. This includes farmers, gardeners, or children who play on lawns where pesticides were used."

Andrew Kniss, associate professor in the Department of Plant sciences at the University of Wyoming agrees, "This is the key point in my opinion. All evidence (however weak) for glyphosate being carcinogenic are from extremely high exposures (occupational levels to unrealistic levels). The exposure that a home user of Roundup or someone eating food would never reach levels of concern."

After examining the IARC report in detail, in 2016, the EPA announced that they found flaws in the IARC study and concluded that glyphosate is not likely to be carcinogenic to humans.[44, 45] In 2017, *Reuters* and *Mother Jones* magazine reported that the scientist who led the IARC's review panel on glyphosate, had access to data from a large study that strongly suggested that Roundup did not cause cancer after all—but he withheld that data from the RoundUp review panel.[46]

The IARC report has had political repercussions. Although glyphosate has long been approved for use in the European Union to clear field of weeds before planting and in orchards, some EU politicians have advocated a ban on its use.[47] In response to the proposed ban, some British farmers supported "Brexit," leaving the European Union.[48] "More than 2 million hectares of land were treated with glyphosate in England and Wales in 2014. Without it, winter wheat and barley production would likely decline by about 12% and cut cultivation of oilseed rape—used for oil and animal feed—by about 10%, according to the National Farmers Union."[47]

Controlling Weeds Without Chemicals

Organic farmers employ a variety of strategies to control weeds. In addition to soil solarization described by Raoul in Chapter 2, they till their fields frequently. Some backyard organic gardeners use a "magical, natural, weed killing potion"[49] as alternatives to chemical weed killers." Anrew Kniss, a professor at the University of Wyoming provides the recipe on his blog[50]:

½ gallon of vinegar
½ cup of salt
2 Tbsp. of dish soap

He writes, "Vinegar contains acetic acid, a chemical (yes, a chemical) with well-known herbicidal properties; it is commonly used by organic gardeners and farmers as a herbicide. The knowledge that salt (sodium chloride, usually) has herbicidal properties goes way back. Soap (even soap is a chemical) is added to increase the spreading of droplets on the weed leaf surface. Most commercial herbicides also contain soaps for this purpose, although we usually refer to them as *surfactants* in that context. The combination of acetic acid, salt, and soap can kill many annual weeds, especially if applied when the weeds are small." Kniss' analysis indicates that this chemical cocktail used by organic farmers is almost 10 times more lethal to mammals than glyphosate.

I agree that it would be nice if farmers could control weeds without spraying chemicals, but weeds remain a big problem for farmers, and there is no simple solution to weed control. Some organic growers flame the weeds or add a chemical vinegar, salt, and soap mixture. However, these methods also have drawbacks (see Box 5.2). Raoul tells me that weeds are the main reason why organic rice yields are often lower than conventional yields (see Chapter 2).

I explain this to Anne, adding, "The good thing about glyphosate is that it is classified by the EPA as nontoxic to fish, humans, and birds and does not accumulate in water or soil. Most other herbicides persist in the environment" (see Box 2.2 in Chapter 2).

"But even if the herbicide is nontoxic, I have read that there is a surfactant mixed with the herbicide that can harm fish," Anne responds.

In some of its commercial forms, glyphosate is mixed with a compound called a surfactant that makes it more effective. Although glyphosate is nontoxic to freshwater fish, there is evidence that a surfactant called POEA, which was included in some formulations, is toxic to aquatic species.[51] This surfactant has been eliminated from most formulations.

I persist on a different tack, "If it is the surfactant you object to, wouldn't it have made more sense to ban the surfactant or even the herbicide itself?"

Our polite discussion increases in pace and volume. She responds, "It would be a political dead end to ban the herbicide because a lot of people use Roundup in their gardens." It seems to me that she is saying that the herbicide on a small scale is acceptable, but for farmers (i.e., on a large scale), it is not, and that because it is popular, we cannot ban the herbicide, only the genetically engineered plants that are tolerant of it.

I am discouraged. If even my smart sister-in-law is lumping so many disparate issues together and does not think these distinctions are important, what chance is there that scientists and farmers will be able to communicate the complex issues involved to other interested consumers? Not so diplomatically, I suggest that she may have read only the Marin campaign materials and may not be fully informed.

She fires back, "I have read for more than 50 hours about this issue and am more informed than most." I realize that this is true. Before her third child came along, she used to work as an environmental lawyer and is accustomed to digging deep into subjects that interest her and forming her own opinion.

I hate to feel that I have to convince my sister-in-law of this or of anything for that matter, but this point seems important. Citizens should vote on the merits of a specific issue and not be influenced by unrelated issues, such as the perceived overuse of herbicides. Am I being unfair to persist for so long? Why can't I just relax and have faith that it will start snowing soon and enjoy the beauty of the mountains and her companionship? Maybe it is impossible to reconcile science and politics anyway—isn't this the point of disagreement? However, we have been cooped up too long, so I plunge deeper into it.

"But what about China? Cotton farmers there have massively reduced their insecticide sprays after planting Bt cotton," I say, "Aren't you pleased about that?"

We talk about the results in China, where the gene coding for the Bt toxin was genetically engineered into cotton, making the plant resistant to serious insect pests such as cotton bollworm that can destroy the crop (Box 5.3). Planting of Bt cotton reduced insecticide use by 123 million pounds over 16 years, an amount that is comparable to what is sprayed annually in the state of California (194 million pounds in 2013).[52–56] Bt corn growers in the United State have reduced insecticide sprays 10-fold in the past 15 years.[15]

Anne responds, "I am certainly very concerned about insecticide use, but we can't ban those either because everyone is used to them now and are familiar with the risks. Again, it just won't fly politically. Besides I don't think the Bt toxin has been adequately tested."

I dispute this point, "Bt toxin has been used by organic farmers for more than 50 years. Look at Raoul. He is healthy."

Anne is not impressed with my statistical sampling, so I go on to explain that the Environmental Protection Agency has found no human health hazards associated with the use of Bt toxins,[57] nor do Bt toxins have any known effect on mammals, birds, and fish. The EPA has found Bt toxins to be of such low risk that it has exempted them from food residue tolerances, groundwater restrictions, and special review requirements—one of the reasons organic farmers like to use them.

BOX 5.3 **Crops Genetically Engineered for Insect Resistance**

What is Bt?

The soil bacterium *Bacillus thuringiensis* (Bt) produces proteins called *cry* that kill plant pests such as caterpillars and beetles. Bt toxins cause little or no harm to most nontarget organisms, including beneficial insects, spiders, wildlife, and people. For these reasons, organic farmers have used Bt sprays and other formulations as their primary method of pest control for 50 years.[58,59]

How Do Breeders Create Bt Crops?

Bt crops were created by inserting the bacterial gene encoding the Bt toxin into the plants' genetic material.

Are Bt Crops Safe To Eat?

The EPA and FDA considered 20 years of human exposure in assessing human safety before agreeing to register Bt corn for commercial use. In addition to these data, numerous toxicity and allergenicity tests were conducted on many different kinds of naturally occurring Bt toxins. Based on these tests and the history of Bt use on food crops by organic farmers, government agencies concluded that Bt corn is as safe as its conventional counterpart and therefore would not adversely affect human and animal health or the environment.[60]

Why Do Farmers Plant Bt Crops?

First commercialized in 1996, Bt crops have become the most commonly grown transgenic crops in the world.[15] Farmers planted Bt cotton on 75% of US acreage in 2013 because it is effective in controlling pests such as tobacco budworm, cotton bollworm, and pink bollworm.[15] Bt corn—which controls the European corn borer, the corn rootworm, and the corn earworm—was planted on 81% of corn acres in 2015. Bt toxin sprayed on leaves quickly degrades in sunlight and does not reach insects feeding inside plants; Bt crops make the toxins internally. Bt crops are effective against insects that bore into stems, such as the European corn borer, which causes more than $1 billion in damage annually in the United States and Canada.[61]

Planting of Bt Crops Reduces Spraying of Chemical Insecticides

In the United States, farmers who plant Bt crops apply fewer chemical insecticides. Corn insecticide used by Bt seed adopters and nonadopters has decreased—only 9% of all US corn farmers used insecticides in 2010[15]. Insecticide use on corn farms declined from 0.21 pound per planted acre in 1995 to 0.02 pound in 2010.[15] This 10-fold decrease in insecticide application is consistent with the steady decline in European corn borer populations over the past decade that has been a direct result of Bt crop adoption.[15] Planting Bt cotton and Bt corn continues to be more profitable, as measured by net returns, than planting conventional seeds.

In India and China, farmers growing Bt cotton have reduced their use of pesticides dramatically,[55,62,63] and the number of pesticide-related poisoning has decreased in farms growing Bt rice.[64] Planting of Bt cotton also reduced pesticide poisonings of farmers and their families.[55,56] Farmers in India growing Bt cotton increased their yield by 24%, their profit by 50%, and raised their living standards by 18%.[65] In 2017 nearly 6000 farmers in Bangladesh planted Bt eggplant to control the the fruit and shoot borer (FSB) caterpillar. "Research has shown that farmers spray between 20–70 times over the growing season in the Philippines for control of FSB," said Anthony Shelton, Cornell University international professor of entomology. "With the pest control offered by Bt eggplant, these sprays can be eliminated."[66,67]

Effect of Bt Crops on Beneficial Organisms

In 2012, 70% to 90% of American, Indian, and Chinese farmers grew Bt cotton.[68] A team of Chinese and French scientists reported that widespread planting of Bt cotton in China drastically reduced the use of synthetic insecticides, increased the abundance of beneficial organisms on farms, and decreased populations of crop-damaging insects.[53,58,63,64] US farms that have cultivated Bt cotton have twice the insect biodiversity of neighboring conventional farms.[68]

Socioeconomic Impacts of Planting Bt Crops

The economic benefits of planting Bt cotton extend beyond the farm and into the community. For example, Matin Qaim, Professor of International Food Economics and Rural Development, and colleagues reported that villages in India that planted Bt cotton received net increases in income at all social levels, not just farmers, and that women have particularly benefited from its adoption.[55,56,63,65]

Planting of Bt Crops Reduce Mycotoxin Posionings

Planting of Bt corn can improve human and animal health by reducing contamination of food by mycotoxins, which are toxic chemicals produced by fungi.[59,69] Bt corn is less susceptible to insect damage that promotes fungal growth. In the United States, Mexican-American women living in the Rio Grande border region consume a diet heavy in corn tortillas. Consumption of tortillas made from mycotoxin-contaminated corn increases the risk of a neural tube defect during the first trimester of pregnancy because the mycotoxin interferes with folate uptake from maternal tissues. The risk of neural tube defects can be reduced by consuming corn tortillas produced from Bt corn varieties.[58]

Mycotoxins can also cause esophageal and liver cancers in humans and are associated with stunted growth of children. These problems are especially acute in rural Africa, where farmers store a year's supply of corn in wicker cribs that are open to the sun, weather, infestation by beetle and weevil larvae, and fungal contamination.[69]

Evolution of Insect Resistance to Bt

Since the 1850s, scientists have noted that planting a single crop variety renders the crop vulnerable to disease outbreaks. One drawback of using any pesticide, whether it is organic, synthetic, or genetically engineered, is that pests can evolve resistance to it. For example, one crop pest, the diamondback moth *(Plutella xylostella)*, a global pest of vegetables, has evolved resistance to Bt toxins in the field.[70] This resistance occurred in response to repeated sprays of Bt toxins to control this pest on conventional (non–genetically engineered) vegetable crops.[71]

Based on this case of field-evolved resistance, laboratory-selected resistance to Bt toxins in other pests, and computer modeling, scientists predicted that evolution of resistance in pests could reduce the effectiveness of Bt crops. Scientists asked the US Environmental Protection Agency (EPA) to mandate a strategy for delaying pest resistance before releasing the Bt crops in the United States. In response, the EPA initially mandated that a minimum of 20% to 50% of total on-farm corn be planted as non-Bt corn within one-half mile (0.8 km) of Bt fields as a structured refuge for the susceptible European corn borer.[72,73] This "refuge strategy" approach, planting crops that do not make Bt toxins on part of the farmland, is an important element of long-term insect resistance management because it promotes survival of susceptible insects.

In a 2017 analysis of 36 studies from ten countries, Bruce Tabashnik, Professor in the Department of Entomology at the University of Arizona, and colleagues found that although most pest populations remained susceptible to Bt, field-evolved resistance to Bt has increased.[74] The increase in documented cases of resistance since 2005 likely reflects increases in the area planted to Bt crops, the cumulative duration of pest exposure to Bt crops, the number of pest populations exposed, and improved monitoring efforts.[74]

"A silver lining is that in 17 other cases, pests have not evolved resistance to Bt crops," Tabashnik said, adding that some crops continue to remain effective after 20 years. The remaining three cases are classified as "early warning of resistance," where the resistance is statistically significant, but not severe enough to have practical consequences.

Tabashnik and colleagues noted that the Environmental Protection Agency has relaxed its requirements for planting refuges in the United States despite the significant risk of some pests evolving resistance to Bt.[75] For example, the minimal percentage of corn acreage planted to non-Bt corn refuges has been reduced from 20% to 5%, and the requirement to plant non-Bt cotton refuges has been abandoned in most regions. They found that although the refuge strategy has been successful for delaying resistance to Bt crops in pests with high inherent susceptibility to Bt toxins, rapid evolution of resistance has been observed in pests with low inherent susceptibility. These observations indicate that some pests may rapidly overcome most or all Bt crops available to control them. To sustain effectiveness of Bt crops against such problematic pests, they recommend an increase in refuge size and integration of Bt crops with other strategies for insect resistance management, such as crop rotation or deployment of plants expressing a diversity of Bt traits. Part of the solution could be incorporation of tiny insecticidal proteins (TIPs) discovered by Schellenberger et al. in 2016. TIP engineered corn were highly resistant to rootworm injury in field trials.[76] Integrated approaches can reduce selection for resistance and may help to delay the further evolution of Bt resistance in pests.[77] These results highlight a basic principle of agriculture: farmers cannot rely on seed alone to control pests and disease.

"Well, one person spraying it is different from millions of people eating it. What if people start to have allergic reactions?" she asks.

Even with such widespread use of Bt toxin–based sprays in the past 50 years, only two incidents of allergic reaction have been reported to the EPA, and they were reactions to the sprays used by organic farmers, not to a Bt crop. In the first incident, investigators concluded that the exposed individual was suffering from a previously undiagnosed disease. The second involved a person who had a history of life-threatening food allergies. On investigation, it was found that the formulation of the Bt spray also contained carbohydrates and preservatives, which have been implicated in food allergies.[78] This is one reason that some scientists conclude that it is safer to genetically engineer Bt toxin in the plant than to use it as a spray it as organic farmers now do.[79]

The risks people associate with Bt toxin are connected with how it is presented. In one of my classes, I asked my students which agricultural products they would avoid (Box 5.4). The list included foods made through genetic engineering and "tomato fruit sprayed with bacterial spores carrying a toxin that kills insects." Many of the students concluded that they definitely would not eat this product. "It sounds awful," one student said. She was surprised to learn that such Bt toxin sprays are commonly used by organic growers and are widely considered safe.

BOX 5.4 **Which of These Genetically Engineered Products Would You Accept?**

- Soybeans that make more monounsaturated fatty acids and fewer polyunsaturated and *trans*-fat fatty acids, providing healthier sources of vegetable oil
- Rice and corn that contain vitamin A needed to prevent blindness and save lives of children in many developing countries
- Paint from genetically engineered soybeans, eliminating the need for chemical modifications that produce toxic byproducts
- Milk produced by cows fed on corn that contains the Bt toxin gene
- Cheese made with rennet produced by genetically engineered microorganisms instead of being extracted from a calf's stomach
- Mangoes from South America produced by a genetically engineered tree that slows ripening (now mangoes can be shipped to the United States, generating more profit for poor farmers)
- Locally grown genetically engineered papayas that are immune to papaya ringspot virus and are cheaper than organic papaya, which can carry large amounts of viral RNA and protein when infected

- Cotton shirts made from genetically engineered cotton that are sprayed with fewer harmful insecticides
- Tomato fruit sprayed with bacterial spores carrying a toxin that kills insects
- Wine from grapes produced by genetically engineered vines that are resistant to the glassy winged sharpshooter
- Tofu made from genetically engineered soybeans that carry a bacterial gene making them resistant to a herbicide classified by the EPA as nontoxic
- Tofu made from non–genetically engineered soybeans that have been sprayed with more toxic herbicides
- Genetically engineered peanuts with reduced allergenicity
- Beef from cows fed genetically engineered corn with improved protein content (i.e., high-lysine corn)
- Low-nicotine cigarettes made from genetically engineered tobacco
- The anticancer drug Taxol produced from genetically engineered corn
- Human insulin made by genetically engineered microorganisms using fermentation
- Human insulin made by genetically engineered plants in the field, which is one half of the price of that made by microorganisms

Modified from Chrispeels, M.J., and D.E. Sandava,. *Plants, Genes, and Agriculture*, 2nd ed. Burlington, MA: Jones & Bartlett Publishers, 1994, 478 p.

I hope to convince Anne that there are some potential benefits of genetic engineering, "Some pests cannot be consistently controlled using organic methods. Most ears of organically grown sweet corn carry fat worms and their *frass*, the stuff that comes out of the backend of the insect. Wouldn't you rather eat Bt corn carrying trace amounts of Bt toxin than eat corn carrying such surprises?"

"I can shop at stores that chop off the wormy bit so that I don't have to." Anne replies.

I have to concede that she has a point there. Clearly, different communities have different preferences and incomes. Many eggplant farmers in Bangladesh, for example, grow Bt eggplant because it allows them to drastically reduce insecticide sprays that can be harmful to their children (see Box 5.3 and Chapter 13). The Amish people of Pennsylvania, known for their use of simple, appropriate technology and organic farming methods, have chosen to grow genetically engineered tobacco because they are able to sell it for a high price, and the community harvest supports their way of life (Box 5.5). In Marin, the wealthiest county in the nation, consumers prefer organic food without worms and are willing to pay for it, but should laws be imposed to regulate such diverse preferences?

BOX 5.5 Amish Growing Genetically Engineered Tobacco

The Amish people of Pennsylvania have evaluated the usefulness of genetically engineered crops. One report indicates that more than 600 Amish families in Pennsylvania signed up to cultivate 3800 acres of transgenic tobacco with reduced nicotine content—enough to produce 345 million cigarettes.[80] The influx of cash was a boon to the community. Instead of earning $400 per acre growing corn, they earn $3500 per acre growing the genetically engineered tobacco. This high-value crop may also benefit some consumers if the reduced-nicotine content helps them quit smoking. Amish farmers also plant Bt corn because they can spray fewer chemicals.[81]

I notice that the yellow cornmeal Anne is using is "enriched and degermed" so I try yet another approach. "Anne, that cornmeal is highly processed. Synthetic chemicals were added to boost nutrition. The corn was probably genetically engineered. None of that is natural. Do you still feel comfortable using it?"

She is startled. "Well, I know I will not drop dead tomorrow; I am not that worried. I trust that the regulators won't let it kill us" (Box 5.6).

My brother Rick wanders in to check on the chili he is making and says, "It doesn't matter what scientists think. If shoppers think it will hurt them, they are not going to eat it."

BOX 5.6 Regulatory Oversight of Genetically Engineered Crops

Before commercial introduction, genetically engineered crops must conform to standards set by state and federal statutes. Under the Coordinated Framework for the Regulation of Biotechnology, federal oversight is shared by the US Department of Agriculture,[15] the US Environmental Protection Agency (EPA), and the US Food and Drug Administration (FDA).

The USDA's Animal and Plant Health Inspection Service (APHIS) plays a central role in regulating field testing of agricultural biotechnology products.[15] Genetically engineered plants, microorganisms, and invertebrates are considered to be *regulated articles*. The APHIS determines authorization of the test based on whether the release will pose a risk to agriculture or the environment. After years of field tests, an applicant may petition the APHIS for a determination of nonregulated status to facilitate commercialization of the product. If, after extensive review, APHIS determines that the unconfined release does not pose a significant risk to agriculture or the environment, the organism is deregulated. At this point, the organism is no longer considered a regulated article and can be moved and planted without APHIS authorization.

If a plant is engineered to produce a substance that "prevents, destroys, repels, or mitigates a pest," it is considered a pesticide and is subject to regulation by the EPA. The FDA regulates all food applications of crops, including crops that are developed through the use of biotechnology, to ensure that foods derived from new plant varieties are safe to eat.[15]

The current regulatory system was established in the 1990s. The USDA, EPA, and FDA address new issues as they arise. The American Society of Plant Biologists recommends that the regulatory framework be revised.[82] Specifically, regulatory scrutiny should focus on the potential for new risks, regardless of the method of introduction of the trait, taking into account existing familiarity with the crop species and the trait being introduced.

It is not known how new crop varieties developed with the new technique of genome editing will be regulated.[83] The USDA has stated that some of these techniques fall outside their regulatory authority.[84]

Rick lifts the lid on the pot of steamed broccoli, which I have forgotten about and now resembles a green paste. "Are you planning to cook this until tomorrow?" he asks.

We all laugh as I hurry over to turn off the heat. A little tension in the room is released as if I had opened a window to let the steam out. Anne has not conceded anything. That is not her style. It is not mine either. We are known as the stubborn ones in the family, but we do realize that we share similar views on the importance of food safety and reducing the use of harmful pesticides and have more in common than not. Based on her willingness to make bread with cornmeal from a genetically engineered crop, it seems that we do agree that the genetically engineered corn on the market is safe to consume.

The kids are hungry so I take the cornbread out of the oven. Beneath the smooth yellow surface, all the contradictions of science, agriculture, and politics seem to be hidden. I am surprised that it looks so plain. I dab on a bit of butter, which the steam melts quickly. We each bite into the yellow bread, which is flaky and crumbles in our hands, and agree it is delicious.

RECIPE 5.2

Cornbread

INGREDIENTS

2 Tbsp. of butter
2 eggs
¼ cup of oil made from genetically engineered canola or corn
2 Tbsp. of honey (most honey in stores is from Canadian canola fields, which are 80% genetically engineered)
1 cup of buttermilk
1 cup of meal from genetically engineered corn (freshly ground is preferable)
½ cup of whole-wheat flour (freshly ground is preferable)
½ cup of barley flour (freshly ground is preferable)
½ tsp. of salt
2 tsp. of baking powder

1. Preheat oven to 425°F.
2. Put butter into an 8-inch-square pan, and set in oven while preheating.
3. Beat eggs together.
4. Add oil, honey, and buttermilk to egg mix.
5. Gently mix in dry ingredients.
6. Quickly pour into pan and bake for 25 minutes.

Adapted from Madison, D. *Vegetarian Cooking for Everyone*. New York: Broadway Books, 1997, p. 752.

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Chapter 5: Legislating Lunch

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CHAPTER 6: WHOM CAN WE TRUST?

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