Genetically Engineered Angst

From Frankenstein to Frankenfoods

DOUGLAS POWELL

On May 20, 1999, John Losey and colleagues from Cornell University published a brief letter in the scientific journal, *Nature* (Losey et al. 1999). The report concerned a laboratory study in which the leaves of milkweed plants in a greenhouse were artificially dusted with pollen from corn plants at levels approximating what the researchers thought happened in nature. Some of the pollen was from conventional corn—whatever "conventional" might mean—and some was from corn genetically engineered to contain the protein toxin from the common soil bacterium, *Bacillus thuringiensis*.

Three-day-old Monarch caterpillars were placed on the leaves and allowed to feed for four days. The researchers reported that 44 percent of the Monarch larvae fed leaves dusted with pollen containing *Bacillus thuringiensis* died. No caterpillar died that ate leaves dusted with regular corn pollen or the control leaves. Larvae feeding on the leaves dusted with pollen containing *Bacillus thuringiensis* also ate much less and were less than half the size of larvae that fed on leaves with no pollen. (No attempt was made, however, to compare the pollen coverage of the leaves in the lab to that which might commonly exist in or near a cornfield.)

The authors correctly recognized that the study was limited in applicability and that field tests would be required to determine the significance of these results found in an artificial environment. Upon publication, Dr. Losey was quoted as saying, "We can't forget that Bt-corn and other transgenic crops have a huge potential for reducing pesticide use and increasing yields. This study is just the first step, we need to do more research and then objectively weigh the risks versus the benefits of this new technology" (Cornell University 1999).

Despite his cautionary statement, Losey found his results transformed into tales of mutant killer corn and sacred butterflies. The *New York Times* led on the front-page with a story entitled, Bambi of the Insect World Threatened (Bambi, of course, having a particular cultural resonance for many in North America who grew up on a "Disneyfied" view of nature). To this date, demonstrators from Greenpeace continue to dress-up as Monarch butterflies and feign death simultaneously at a pre-arranged time, usually for the convenience of television cameras. Great street theatre, poor public policy, ignoring that numerous subsequent studies and analyses have concluded that the risk to Monarch butterflies is minuscule, especially when compared to known risks such as destruction of wintering grounds in Mexico.

This combination of scientific *naïveté,* media hyperbole, and allegations of corporate conspiracy has come to characterize public discussions of genetically engineered foods or, as they are sometimes called, genetically modified organisms (GMOs). Such labels can be confusing because all foods are genetically modified, whether through traditional breeding, chemically induced changes, or genetic engineering.

The Pusztai affair

International public discussion of genetically engineered foods increased dramatically through the latter part of 1998. There was, for example, the Pusztai affair.

On August 10, 1998, Dr. Pusztai of the Rowett Research Institute in Aberdeen, Scotland, reported that, after he had fed five rats for 110 days on potatoes genetically engineered to contain one of two lectins known to be toxic to insects, some of the rats showed stunted growth and impaired immune systems. Dr. Pusztai reported his findings not in a peer-reviewed scientific journal but on the *World in Action* television program. After an internal review of the data by Rowett Research Institute, it emerged that not only had Dr. Pusztai ignored the conventional route of scientific peer review but also that the experimental design lacked appropriate controls. Potatoes themselves are full of poisonous chemicals in quantities that vary depending how they are grown, a phenomenon known as somaclonal variation, and must therefore be uniformly grown for any feeding trail to be informative. As well, rats do not like to subsist on raw potatoes and their diet must be supplemented. By August 12, 1998, Dr. Pusztai had been suspended and was subsequently forced to retire.

The Pusztai affair spawned significant media coverage and numerous allegations. On February 12, 1999, a group of twenty international scientists released a letter supporting the work of Dr. Pusztai and specifically charged that the process of genetic engineering itself and, in particular, the use of the 35S cauliflower-mosaic-virus promoter was to blame. The 35S promoter is widely used in the genetic engineering of plants to turn specific genes on and off. Because of this widespread use, regulators in Western countries already demand evidence that any 35S insertion is stable and well understood. Further, other feeding experiments involving the 35S promoter have not found the problems described by Pusztai and supporters (see www.plant.uogueph.ca/safefood/gmo/gmo-index.htm). Most importantly, though, the potatoes grown by Dr. Pusztai would not have passed regulatory scrutiny in Canada, or the United States, or the United Kingdom and would never have been approved. Subsequently, the Royal Society concluded that "Dr. Arpad Pusztai's widely publicized research into the effects of feeding rats Genetically Modified (GM) potatoes appears to be flawed, and it would be unjustifiable to draw from it general conclusions about whether genetically modified foods are harmful to human beings or not" (Royal Society 1999).

Pubic response to GMOs in Canada

Public discussion of genetically engineered foods in Canada increased dramatically in the fall of 1999 (figure 1). Canadian coverage was significantly bolstered when Greenpeace and the Council of Canadians, two activist groups, held a public demonstration in front of a Loblaw supermarket in an affluent area of downtown Toronto. Typical of the statements made by the demonstrators was that of Jennifer Story, health protection campaigner for the Council of Canadians, who asserted that, "Genetically engineered foods have not been proven safe for human health and the environment. As the largest grocery chain in Canada, Loblaw has the obligation to take the lead, and take genetically engineered food off the shelf" (Greenpeace and Council of Canadians (1999).

Such media accounts, regardless of accuracy and tone, influence the formation of public perceptions. There have been many surveys of public opinion about biotechnology in general and, more specifically, about agricultural biotechnology. In his comprehensive history of biotechnology, Bud (1993) begins by asking, "What other single word is itself the subject of worldwide polling?" (for a review, see www.plant.uoguelph.ca/safefood/gmo/gmo-index.htm).

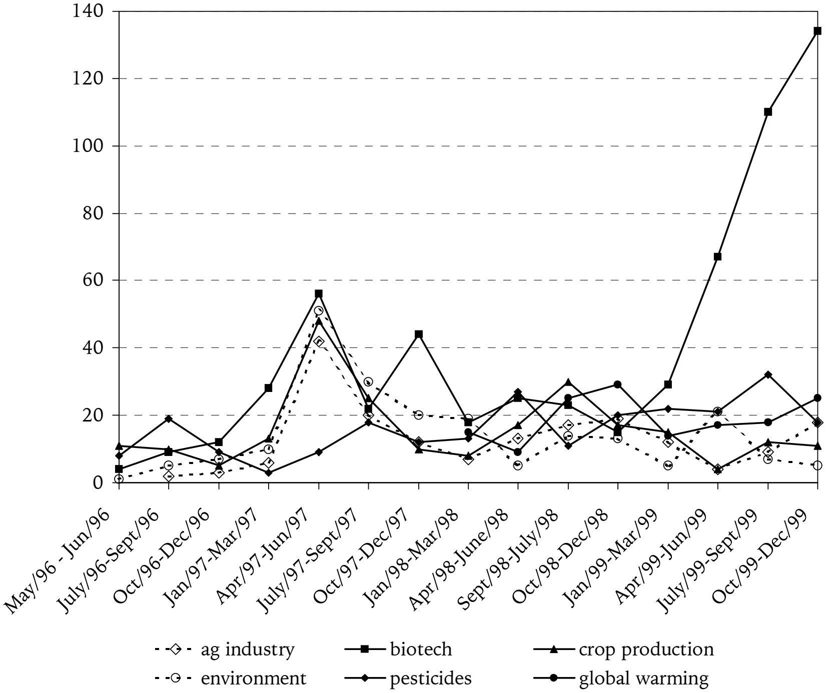


Figure 1 Distribution of top five plant-agriculture stories by topic from *Associated Press*, the *Globe and Mail, Kitchener-Waterloo Record, New York Times* (May 1, 1996 to December 31, 1999; *n* = 1,623)

Although relatively few Canadians have heard or read about biotechnology (Powell 1994; May 2000) opinions regarding specific biotechnology applications have consistently appeared much stronger. Kelley (1995) concluded that Australian voters had firm opinions about biotechnology and noted that in a democracy, voters routinely make decisions about policies about which they have no detailed academic understanding. Consumers will continue to make decisions about biotechnology, whether they are "better educated" or not.

The public notions of agricultural biotechnology, consistently articulated as concerns about uncertainty, playing God, and the involvement of powerful interests, leads to the perception, frequently used in media accounts, of science out of control. Such concerns are valid. Genetic engineering is a powerful technology—and that is the source of potential benefit and unrestrained angst. It is also why the technology is regulated. As Norman Ball of the University of Waterloo (Ball 1992) has noted, all revolutionary technologies create three public responses in succession: unrealistic expectations (all new technologies are oversold), confusion, and, eventually, finding a way to cope. Biotechnology has been greatly oversold but, as with other new technologies, a public discussion over time shifts from one of risks versus benefits to a more realistic approach of extracting whatever benefits a technology can bring while actively and prudently minimizing risks.

From *Frankenstein* to Frankenfoods

Of course, such a pattern of social response to new technologies is hardly novel. First published in 1817, Mary Shelley's *Frankenstein* contained many warnings about science out of control. At a time when fundamental advances in organic chemistry were leading some scientific charlatans to say they had discovered the secret of life, Shelley, a member of England's radical intellectual elite, had Professor Walden, Frankenstein's teacher, say:

> The ancient teachers of this science promised impossibilities and performed nothing. The modern masters promise very little; they know metals cannot be transmuted and that the elixir of life is a chimera. But, these philosophers, whose hands seem only made to dabble in dirt, and their eyes to pore over the microscope or crucible, have indeed performed miracles. They penetrate into the recesses of nature and show she works in her hiding places. They ascend into the heavens; they have discovered how the blood circulates and the nature of the air we breathe. They have acquired new almost unlimited powers; they can command the thunders of the heaven, mimic the earthquake, and even mock the invisible world with its own shadows.

Through the new-found wonders of chemistry, Professor Frankenstein creates a monster that pursues him and, finally, he pays the price for hubris with his life. And, over the years, that is a repeatable pattern—cycles of scientific hubris and humility.

Today, as farmers throughout North America embrace the tools of agricultural biotechnology—in Canada, for example, about one-third of the corn, 20 percent of the soybeans, and 60 percent of the Canola grown in 2000 will be genetically engineered—environmental and activist groups dub the products "Frankenfoods," consistent with the narrative about Frankenstein that resonants deep within humans. Yet despite the rhetoric of "untested" and "Frankenfood bad"—rhetoric designed to alert rather than inform—one can readily substantiate the more accurate claim that genetically engineered foods, in many instances, are better for the environment, contain lower levels of natural toxins and are, indeed, rigorously tested. The first two claims—that genetically engineered foods are better for the environment and contain lower levels of natural toxins—will be discussed later. Of testing though, it can be said shortly that genetically engineered foods are much more rigorously tested than are the so-called conventional foods. (United States National Academy of Sciences 2000).

What is a genetically modified food?

Genes are functional units of deoxyribonucleic acid (DNA) that can encode for proteins or serve a regulatory function affecting the expression of particular genes at a particular time. Genes are arranged along structures known as chromosomes. The characteristics of all living organisms, including humans, are determined by information contained within the DNA inherited from their parents, in concert with environmental interactions. DNA directs how cells develop and controls the way characteristics, such as eye color, are passed on from one generation to the next.

The molecular structure of DNA can be imagined as a zipper. Each tooth of the zipper is represented by one of four letters (A, C, G, or T). These four letters represent the four small molecules, adenine, cytosine, guanine, and thymine, that form the teeth of the DNA zipper. Opposite teeth form either an AT or GC pair. DNA dissolved in water can be "unzipped" by heating and "zipped" by cooling. However, DNA will not zip correctly unless AT or GC pairs are formed (Betsch and Webber 1994).

Since the beginning of the twentieth century, scientists have been cataloging and trying to understand how the 100,000 or so genes in human cells interact with the biochemical environment to create individual human beings, each with their own specific traits such as hair and eye colour, fingerprint patterns, and so on. Similarly agricultural scientists have been working to understand the genetic basis of various traits in plants and animals. Biotechnological methods of genetic engineering are relatively new techniques that plant breeders use to make direct modifications of DNA, a living thing's genetic materials. Scientists make copies of genes for desired traits and introduce the gene copy into an organism such as a food crop. The new gene is usually a single gene whose function is well understood, such as a gene that carries tolerance for herbicides or resistance to insects. These new techniques avoid one of the major problems encountered by plant breeders who use cross hybridization: no unwanted or undesirable genes are introduced along with the desired gene. In addition, scientists can make copies of genes from any organism—plant, animal, or microbe—that may yield a desired trait and introduce that gene into a food crop.

Regulation of biotechnology

The structure and nature of DNA was elucidated in the decades between 1940 and 1960 and geneticists Cohen and Boyer created the first genetically engineered organism in 1975. In 1974, a self-imposed moratorium by the scientific community, led by Paul Berg, on experiments in genetic engineering and the subsequent Asilomar conference in California (February 1975), largely concerning the risks from genetic engineering in terms of laboratory safety and accidental escape, led to wide-spread public debate. The moratorium was lifted the following year, when the United States National Institutes of Health (NIH) issued guidelines for experimentation with genetically engineered organisms (Davis 1991; Krimsky 1991). The European Commission issued similar guidelines (Cantley 1999). The Genetic Manipulation Advisory Group was formed in the United Kingdom while the NIH formed the Recombinant DNA Advisory Committee in the United States. Each group developed regulations for federally funded research. After years of safety research, in 1986 the Organisation for Economic Cooperation and Development (OECD) determined that "there is no scientific basis for specific legislation to regulate the use of recombinant organisms" (OECD 1993). The World Health Organization and OECD, in conjunction with thousands of governmental and academic experts working over the past 20 years, have developed regulations and guidelines for plant biotechnology (Groote, Feldbaum, and Arke 1999).

Mutagenesis

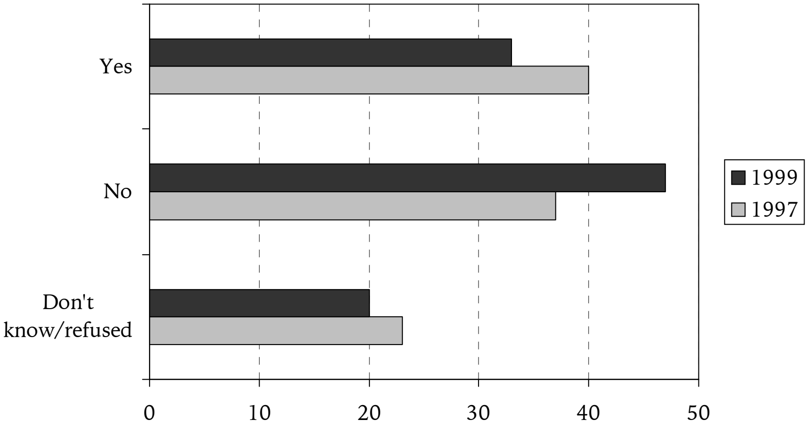
Genetic variability is required to enhance traits deemed desirable by humans. Geneticists can travel the world searching for plants, animals, or microorganisms that posses a trait of interest such as increased productivity or disease resistance. Desirable variability can be selected over generations of breeding. Genetic engineering, using the tools of molecular biology, allows further sources of genetic variability to be introduced into a particular organism.

There are, however, other techniques to create genetic variability between the black-and-white of traditional breeding and genetic engineering. Since the 1940s, mutagenesis breeding has been used to induce genetic variability, especially in the cereals, by exposing seeds to doses of mutagens—compounds that induce mutations in DNA—such as ionizing radiation or mustard gas. The practice is still used today as are other techniques. Should such products also be regulated? Or, is it the process of genetic engineering itself that is inherently risky. Proponents and critics have sparred on this point since the advent of genetic engineering but the scientific community and North American regulators have consistently maintained that it is the end-product, not the process, that should be regulated. Varieties of potatoes and celery, for example, have been produced through traditional breeding that were later discovered to contain unacceptably high levels of natural compounds. The view that the end-product should undergo a safety assessment regardless of how it was produced has been enshrined in the Canadian Novel Food Act (1999) and was more recently reaffirmed by an expert panel of the United States National Academy of Sciences (2000).

Opinion and products

When asked if food products of biotechnology are available in supermarkets, Americans answer "yes," "no," and "I don't know" (figure 2), again evidence of the confusion wrought by technological change. But, when asked what products were available, Americans (IFIC 1999) listed vegetables, tomatoes, and produce as the top three items (figure 3). Yet, it is the bulk commodities—corn, soy, and Canola—that make up the bulk acreage of genetically engineered crops in both Canada and the United States. Genetically engineered whole tomatoes are unavailable in both countries. Yet, people think they are, for two reasons. First is the association with the FlavrSavr tomato, briefly released for commercial sale in 1994 after prolonged public and media discussion. Second, and more important, is that consumers are repeatedly asked: "Do you want fish genes in your tomatoes?" This evocative example is repeat-

Figure 2 Responses to the survey question: "As far as you know, are there any foods produced through biotechnology in the supermarket now?" (n = 1,000)



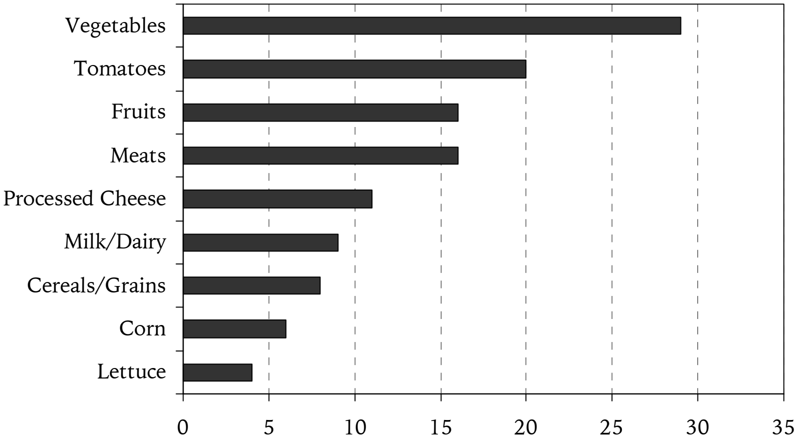
Source IFIC 1999.

edly used by Greenpeace and others in campaign literature and media accounts. Yet the actual experiment to transfer an anti-freeze protein from cold-water flounder to enhance the tolerance to cold of field tomatoes was only attempted once in 1991 and was unsuccessful (see www.plant.uoguelph.ca/safefood/gmo/gmo-index.htm).

Another evocative example is the purported risk to Monarch butterflies posed by genetically engineered Bt-corn. And, despite the continual accumulation of evidence that Monarch butterflies are indeed safe from such crops, media and activist groups continually cite growing evidence of risk. This is simply not true.

One of the first products of biotechnology to make a significant commercial impact in Canada has been insect-resistant corn, containing the d-endotoxin produced by *Bacillus thuringiensis* and generally referred to as "Bt-corn." *Bacillus thuringiensis* (Bt) is a gram-positive soil bacterium that produces an insecticidal protein in the form of a crystal. The insecticidal proteins are commonly designated as *cry* proteins and the genes encoding the proteins are known as *cry* genes (Lambert and Peferoen 1992). The Bt toxin is regarded as an environmentally friendly insecticide because of its target specificity and its decomposition to non-toxic compounds when exposed to environmental factors (Gould 1995). *Bacillus thuringiensis Berliner* is the most commonly used biopesticide (Wearing and Hokkanen 1995). Bt has been widely used in both

Figure 3 Responses to the survey question: "Which foods produced through biotechnology are currently in the supermarket?" (*n* = 331; multiple answers accepted)



Source IFIC 1999.

conventional and organic farming operations as an insecticidal spray with some drawbacks. In order for the Bt endotoxin to be effective, the insect must ingest it before it is broken down by environmental factors such as ultraviolet light or drought conditions (Webber 1995). One advantage of genetically engineered Bt-corn is that the insecticidal protein has been incorporated into the plant, limiting environmental exposure. Insecticidal properties of Bt can vary in activity against insects within a single insect order. The toxins encoded by the *cry*I genes are toxic to *Lepidopterans* such as the European corn borer (ECB), *Ostrinia nubilalis*. Various specific Bt-toxins have also been genetically engineered into potatoes and cotton, both of which have been approved for consumption in Canada.

Ostrinia nubilalis, the European corn borer, is a common pest in corn fields across Ontario, as well as other areas of concentrated corn production such as the American states of Minnesota and Iowa. There are risks associated with genetically engineered corn, predominantly the acceleration of the development of resistance in the target pest. Recognizing this, scientists in universities and industry have worked for years to develop management strategies to delay the development of resistance in the European corn borer.

The most frequently recommended management strategy is the use of *refugia*: when Bt crops are planted, a small section of the field is sown with non-transgenic crops to provide a "refuge" for susceptible insects to breed. Since these insects would not be in contact with the toxin, the selection pressure for rare resistant individuals would be removed. The constant supply of susceptible insects would then interbreed with the resistant insects flying amongst the transgenic crops, thereby diluting the number of resistant individuals in the population. The *refugia* strategy is combined with a "high-dose" strategy, yielding a "high-dose-plus-*refugia*" management scheme. The dose refers to the level of expression of Bt in the plants: a high dose refers to toxin expression at 25 times the dose required to kill 99 percent of insects under normal conditions (LD99) and will kill most insects while a midrange or low dose will only kill some insects, thereby selecting for those that are resistant. A paper in March 2000 (Shelton, Tang, Roush, Metz, and Earle 2000) provided the first field evidence to validate predictions made by computer and by field-test that *refugia* appear to work at managing the development of resistance in the target pest.

Other management strategies have also been proposed. Among these schemes are rotation of plantings between transgenic and non-transgenic crops (in the years when non-transgenic crops are planted, use of other insecticides would be required); mixing seeds so that each field contains a variety of crops, each carrying different toxin genes;

engineering two or more toxin genes into a single plant (the two latter strategies assume other toxin genes have been identified and are effective); modifying the transgene such that the toxin is only produced in certain plant parts or at certain times during plant development.

The study by Losey et al. (1999) on possible impacts on Monarch butterflies attracted widespread media coverage as well as rebuttals and criticisms in the scientific press (Beringer 1999; Fumento 1999; Hodgson 1999). According to Shelton and Roush (1999), a previous and more relevant and realistic field study (Hansen and Obrycki 1999) had been largely overlooked. Further, the results of Losey et al. (1999) were far from unexpected, contrary to media assertions. When Bt-corn was approved in the United States and Canada, regulators and scientists reasoned that the impact of Bt-corn—or, more correctly, the pollen from Bt-corn containing active toxin—on Monarch populations would be minimal, given that milkweed, the desired food of Monarch larvae, is rarely found in corn fields but in adjacent fields, that the toxin is rapidly inactivated by ultraviolet light and drought conditions, and that non-discriminate spraying for other corn pests may present a significantly higher risk to the Monarch population through chemical drift.

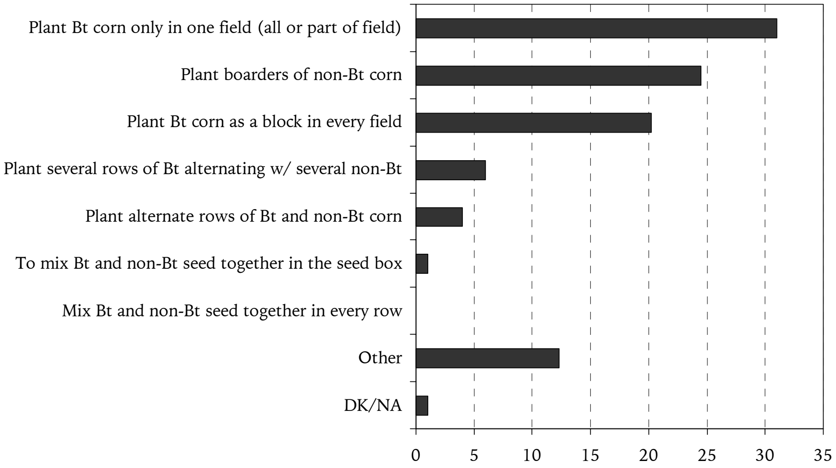
In response to the report from Cornell, a consortium of biotechnology and pesticide companies—the Agricultural Biotechnology Stewardship Working Group (ABSWG)—funded 17 studies to quantify the risk of Bt-corn to Monarchs (Weiss 1999; Currie 1999). The research was conducted during the summer of 1999 at universities in corn-producing regions of North America (BIO 1999). Data presented at a meeting in November 1999 indicated that not all strains of Bt-corn are equally toxic (Brower and Zalucki 1999); some varieties of Bt-corn may, in a theoretical or laboratory setting, harm the butterfly while other types may not (Currie 1999). Furthermore, it was suggested that the amount of pollen migrating to milkweeds was "likely to be dangerous to only those monarchs feeding on milkweeds within or close to the edges of the cornfields" (Brower and Zalucki 1999). Although researchers have much to learn about the ecological consequences of Bt-corn on Monarch butterflies, the findings of the meeting were, according to media accounts and discussions with some participants, generally positive.

Stuart Weiss, a Stanford University expert in ecological modeling, was quoted as saying: "the worst-case scenario of this toxic cloud of pollen saturating the corn belt is clearly not the case." Mark Sears, chair of the department of environmental biology at the University of Guelph and chair of the Ontario Corn Borer Coalition, reported that virtually all pollen grains land within 10 yards from the field, 90 per cent of which travel less than five yards (Weiss 1999). Sears postulated that the risk of the hazard to Monarch larvae is minimal, especially after discovering that at least 500 grains of pollen per square centimeter of milkweed leaf was necessary to sicken caterpillars. After three days of accumulation during pollination season, Sears found this concentration was barely attained on nearby milkweed leaves.

Iowa State University's John Pleasants found that wind direction, rainfall and other factors significantly affect pollen concentrations on milkweed. Pleasants found that "88 per cent of milkweed within one meter of a corn field would fall below the level where they could hurt the caterpillars and 100 per cent of the milkweed just two meters from a Bt field would be monarch-safe" (Kendall, 1999). Such findings on pollen dispersion are especially significant when coupled with planting preferences. Powell et al. (1999) found that planting the borders of a corn field to non-Bt-corn was the second most prevalent implementation of Bt-*refugia* guidelines among 400 Ontario corn producers who planted Bt-corn in 1999 and the most common practice among those with more than 100 acres of corn (figure 4).

Further, a more recent study from scientists at the University of Illinois suggests that non-target effects of genetically engineered Bt-corn may be less severe than previously reported. Among the other insects at potential risk of exposure to pollen from Bt-corn is the black swallowtail butterfly, *Papilio polyxenes,* whose host plants in the mid-

Figure 4 Ontario farmers' choice of seven planting patterns for seeding Bt and non-Bt-corn (n = 400)



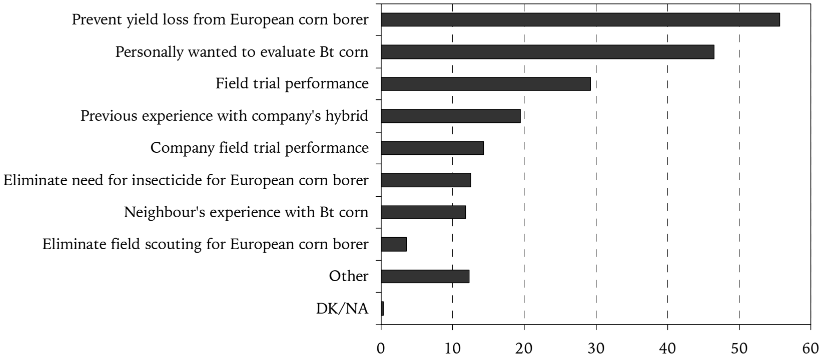
Source Bt-corn survey.

western United States are located mostly in narrow strips near crop fields. Results of a field study investigating the affect of Bt-corn pollen on the mortality of the black swallowtails was published in the June 6, 2000 issue of the *Proceedings of the National Academy of Science* (PNAS). The researchers concluded that Bt-corn pollen from the variety tested is unlikely to harm wild populations of black swallowtail butterflies.

Such findings rarely make it into mainstream media, despite aggressive efforts by some farm groups and others; further, these findings are rarely, if ever, acknowledged by critics of agricultural biotechnology. Instead, groups like Greenpeace insist that "farmers are being duped." The basis of this assertion is apparently anecdotal evidence. Powell, Grant, and Lastovic (1999) found that when 400 Ontario growers of Bt-corn were asked in 1999 why they invested in the more expensive seed, the number-one reason was higher yield, followed by a desire to evaluate personally the technology (the latter had been the number-one reason in 1998). In short, farmers, knowing that all new technology is oversold, wanted to evaluate what worked on their farms and in the conditions on their land, hardly the attributes of someone being "duped" (figure 5).

Entomologists estimate that losses resulting from damage by the European corn borer (ECB)and the costs of controlling the pest exceed $1 billion each year (Ostlie, Hutchison, and Hellmich 1997; Dekalb 1998; Andow and Hutchison 1998; Haag 1999). ECB typically go through two life-cycles during the corn-growing season, and the second generation usually causes the most damage. In 18 tests over the last six years, researchers from Iowa State University found losses due to ECB of

Figure 5 Ontario farmers' reasons for planting Bt-corn hybrids, 1999 (*n* = 400)



Source Bt-corn survey.

4 bushels or more per acre from 94 percent of the fields they examined (Dekalb 1998). Very conservative estimates place the value of Bt-corn at $7 million to $10 million annually in improved corn yields in Ontario in 1998, when about 20 percent of the crop was planted to Bt varieties.

A report released on June 25, 1999 by the United States Department of Agriculture's Economic Research Service (ERS) indicated increased yields of up to 30 percent for Bt-maize versus its non-engineered counterpart (USDA 1999). Increased yields were shown in most applications of Bt-cotton. In July 1999, the National Center for Food and Agricultural Policy in Washington, DC (BIO 1999) released the first study aimed at assessing whether Bt-corn, Bt-cotton, and Bt-potatoes actually yielded benefits. For Bt-corn, the study found that in 1997, when ECB infestation was high, total yields were increased in the United States by 47 million bushels, boosting profits by US$72 million. That year, however, only 4 million acres of Bt-corn were planted. In 1998, when 14 million acres of Bt-corn were planted, though infestation by the corn borer was extremely light, farmers still saw an increase of 60 million bushels.

However, this did not translate into higher profits. While acreage of Bt-corn was three times higher in 1998 over the previous year, growers lost an estimated $26 million because pest-infestation levels had declined and the price of corn dropped well below average. Crops of Bt-cotton accounted for 17 percent of the total cotton crop in the United States in 1998 and it boosted total yields by 85 million pounds (see www.bio.org/food&ag/bioins01.html).

Benefits to human health

Feeding on maize kernels by ECB often leads to infection by fungi in the genus *Fusarium*, including the fumonisin-producing species (Munkvold et al. 1999). Fumonisins are a class of mycotoxins and esophageal cancer in humans has been associated with consumption of maize with high concentrations of the fumonisins (Munkvold et al. 1999). Recent research by the United States Department of Agriculture (2000) shows a reduction in mycotoxins of 30 to 40 times in Bt-field-corn compared to non-Bt-corn.

Such a discussion of risk and benefit can be developed for all technical questions about genetically engineered foods. Space constraints limit the examples but further elaborations can be found at www.plant.uoguelph.ca/safefood.

As technologies mature, the public discussion also matures from one of all benefit and all risk to one of managed risk. The current state of risk management and communication research suggests that those responsible with food-safety risk management must be seen to be reducing, mitigating, or minimizing a particular risk. Those responsible must be able to communicate their efforts effectively and they must be able to prove they are actually reducing levels of risk. As Slovic has noted:

> We live in a world in which information, acting in concert with the vagaries of human perception and cognition, has reduced our vulnerability to pandemics of disease at the cost of increasing our vulnerability to social and economic catastrophes of unprecedented scale. The challenge before us is to learn how to manage stigma and reduce the vulnerability of important products, industries, and institutions to its effects, without suppressing the proper communication of risk information to the public. (Slovic 1997)

Stigma is a powerful shortcut consumers may use to evaluate food-borne risks. Gregory, Slovic, and Flynn (1995) have characterized stigma as:

- the source is a hazard;
- a standard of what is right and natural is violated or overturned;
- impacts are perceived to be inequitably distributed across groups;
- possible outcomes are unbounded (scientific uncertainty); and,
- management of the hazard is brought into question.

These factors of stigmatization certainly apply to the products of agricultural biotechnology. Stigmatization is becoming the norm for food and water linked to human illness or even death. The challenge, then, is to reduce stigma. The components for managing the stigma associated with any food safety issue involve the following factors:

- effective and rapid surveillance systems;
- effective communication about the nature of risk;
- a credible, open and responsive regulatory system;
- demonstrable efforts to reduce levels of uncertainty and risk; and,
- evidence that actions match words.

Appropriate levels of risk management coupled with sound science and excellent communication about the nature of risk are required to garner further benefits of any technology, including agricultural biotechnology.

References

Androw, D.A., and W.D. Hutchinson (1998). Now or Never: Serious New Plans to Save a Natural Pest Control. Chapter 3: Bt-Corn Resistance Management. Union of Concerned Scientists. Anonymous. December 15, 1998. Bt-Corn for Control of European Corn Borer. Insect Pest Management for Field and Forage Crops. Digital document: www.aces.uiuc.edu/ipm/field/iapmh/ipmffcbtecb.html.

Ball, Norman R. (1992). Essential Connections: Past and Future; Technology and Society. In *Proceedings, Beyond the Printed Page: Online Documentation. Second Conference on Quality in Documentation.* Waterloo, ON: The Center for Professional Writing, University of Waterloo: 11–28.

Betsch, D.F., and G.D. Webber (1994). *DNA Fingerprinting in Agricultural Genetics Programs.* North Central Regional Publication (November1). Columbia, MU: Office of Biotechnology, University of Missouri. Digital document: muextension.missouri.edu/xplor/regpubs/ncr554.htm.

Beringer, J.E. (1999). Cautionary Tale on Safety of GM Crops. *Nature* 399: 405.

Biotechnology Industry Organization (BIO) (1999). Scientific Symposium to Show No Harm to Monarch Butterfly. Press release (November 2). Washington, DC: Biotechnology Industry Organization.

Brower, L.P., and M.P. Zalucki (1999). Bt-corn and Its Effect on Monarch Butterflies: A Note of Caution. November 11. E-mail listserve.

Bud, R. (1993). *The Uses of Life: A History of Biotechnology.* Cambridge: Cambridge University Press.

Cantley, M. (1999). Letters. *International Herald Tribune* (August 20).

Cornell University (1999). *Engineered Corn Can Kill Monarch Butterflies.* Press release (May 19).

Currie, B.M. (1999). Altered Corn-Butterflies. *Associated Press* (November 3).

Davis B. (1991). *The Genetic Revolution: Scientific Prospects and Public Perceptions.* Baltimore, MD: Johns Hopkins University Press.

Dekalb (1998). Corn Borers and Bt-corn. December 15. Digital document: www.dekalb.com/dktraits/Btcorn.htm.

Fumento, M. (1999). *The Wall Street Journal* (June 25): 4.

Gould, F. (1995). The Empirical and Theoretical Basis for Bt Resistance Management. *Information Systems for Biotechnology/NBIAP [National Biological Impact Assessment Program] News Report: Special Issue on Bt.* (December). Digital document: www.nbiap.vt.edu.

Greenpeace and Council of Canadians (1999). Press release (September 29). Canada Newswire.

Gregory, R., P. Slovic, and J. Flynn (1995). Risk perceptions, Stigma, and Health Policy. *Health and Place* 2, 4: 213–20.

Groote, J., C.B. Feldbaum, and A. Arke (1999). Letters. *International Herald Tribune* (August 18).

Haag, E. (1999). Is Bt-Corn Right for Silage? *Farm Journal—Daily Today* (March).

Hansen, L., and J. Obrycki 1999. *Non-Target Effects of Bt Corn on the Monarch Butterfly (Lepidoptera: Danaidae)*. Digital document: www.ent.iastate.edu/entsoc/ncb99/prog/abs/D81.html.

Hodgson, J. 1999. Monarch Bt-Corn Paper Questioned. *Nature Biotechnology* 17: 627.

Kelley, J. (1995). *Public Perceptions of Genetic Engineering: Australia 1994*. Canberra: Australian Department of Industry, Science and Technology. Digital document: www.isr.gov.au/pubs/reports/genengin/content.html.

Kendall, P. (1999). Monarch Butterfly So Far Not Imperiled: Gene-altered Corn Gets an Early OK in Studies. *Chicago Tribune* (November 2): 4.

Krimsky, S. (1991). *Biotechnics and Society: The Rise of Industrial Genetics*. New York: Praeger.

Lambert, B., and M. Peferoen (1992). Insecticidal Promise of *Bacillus thuringiensis*. 112–22.

Losey, J.J, L. Raynor, and M.E. Carter (1999). Transgenic Pollen Harms Monarch Butterfly. *Nature* 399: 214.

May, K. (2000). Majority Immune to Biotech Health Scare: Poll—Willing to Take Risks. *National Post* (July 24): A1.

Munkfold, G.P., R.L. Hellmich, and L.G. Rice (1999). Comparison of Fumonisin Concentrations in Kernels of Transgenic Bt Maize Hybrids and Nontransgenic Hybrids. *Plant Disease* 83: 130–38.

Organisation for Economic Cooperation and Development (OECD) (1993). *Safety Evaluation of Foods Derived by Modern Biotechnology: Concepts and Principles*. Paris: OECD.

Ostlie, K.R., W.D. Hutchison, and R.L. Hellmich, Eds. (1997). *Bt Corn and European Corn Borer: Long-Term Success through Resistance Management*. University of Minnesota. Digital document: www.extension.umn.edu/distribution/cropsystems/DC7055.html.

Powell, D., K. Thomas (2000). *A Fish Gene in a Tomato*. Digital document: www.plant.uoguelph.ca/safefood/gmo/dp-thomas-flavrsavr.htm.

Powell, D.A., M.W. Griffiths (1994). Public Perceptions of Agricultural Biotechnology in Canada. Unpublished paper given at the annual meeting of the Institute of Food Technologists, Atlanta (June 25–29).

Powell, D. 1999. *Cauliflower Mosaic Virus Promoter: Potential Risks*. Digital document: www.plant.uoguelph.ca/safefood/gmo/camv35s/camv35s.htm

Powell, D.A., S.E. Grant, and S. Lastovic (1999). *A Survey of Ontario Corn Producers to Assess Compliance with Refugia Recommendations to Manage Development of Resistance to Genetically Engineered Bt-Corn in the European Corn Borer, 1999*. Agrifood Risk Management and Communication Tech. Report 10. Digital document: www.plant.uoguelph.ca/safefood/gmo/bt-survey/bt-survey.html.

Royal Society (1999). GMOs and Pusztai: The Royal Society Reviews the Evidence. Press Release (May 18). Digital document: www.royalsoc.ac.uk/press/pr_15_99.htm.

Shelton, A.M., and R.T. Roush (1999). False Reports and the Ears of Men. *Nature Biotechnology* 17, 9: 832.

Shelton, A.M., J.D. Tang, R.T. Roush, T.D. Metz, and E.D. Earle (2000). Field Tests on Managing Resistance to Bt-Engineered Plants. *Nature Biotechnology* 18: 339–42.

Slovic, P. (1997). Perceived Risk, Stigma, and the Vulnerable Society. Unpublished paper presented at the One-Day Conference on Risk (June 13, 1997), City University, London.

Wearing, C.H., and H.M.T. Hokkanen (1995). Pest Resistance to *Bacillus thuringiensis*: Ecological Crop Assessment for Bt Gene Incorporation and Strategies for Management. In H.M.T. Hokkanen, J.M. Lynch, (eds.), *Biological Control: Benefits and Risks*. Plant and Microbial Biotechnology Research Series. Cambridge: Cambridge University Press: 236–52.

Webber, G.D. 1995. *Insect Resistant Crops through Genetic Engineering*. Biotechnology Information Series (Bio-9). North Central Regional Extension Publication, Iowa State University. Digital document: www.nalusda.gov/bic/Education_res/iastate.info/bio9.html (July10, 1997).

Weiss, R. 1999. Gene-altered Corn's Impact Reassessed: Studies Funded by Biotech Consortium Find Little Risk to Monarch Butterflies. *The Washington Post* (November 3): A3.

United States National Academy of Sciences (2000). US Regulatory System Needs Adjustment as Volume and Mix of Transgenic Plants Increase in Marketplace. Washington, DC (April 5).

United States Department of Agriculture (Economic Research Service) (1999). *Genetically Engineered Crops for Pest Management*. Digital document: www.econ.ag.gov/wahtsnew/issues/biotech (June 25).

United States Department of Agriculture (2000). *Bt Corn: Less Insect Damage, Lower Mycotoxin Levels, Healthier Corn*. USDA-ARS News Service (April 26).