

Food Biotechnology: Benefits and Concerns¹

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ABSTRACT Recent advances in agricultural biotechnology have highlighted the need for experimental evidence and sound scientific judgment to assess the benefits and risks to society. Nutrition scientists and other animal biologists need a balanced understanding of the issues to participate in this assessment. To date most modifications to crop plants have benefited producers. Crops have been engineered to decrease pesticide and herbicide usage, protect against stressors, enhance yields and extend shelf life. Beyond the environmental benefits of decreased pesticide and herbicide application, consumers stand to benefit by development of food crops with increased nutritional value, medicinal properties, enhanced taste and esthetic appeal. There remains concern that these benefits come with a cost to the environment or increased risk to the consumer. Most U.S. consumers are not aware of the extent that genetically modified foods have entered the marketplace. Consumer awareness of biotechnology seems to have increased over the last decade, yet most consumers remain confused over the science. Concern over the impact on the safety of the food supply remains low in the United States, but is substantially elevated in Europe. Before a genetically engineered crop is introduced into commerce it must pass regulatory scrutiny by as many as four different federal regulatory bodies to ensure a safe food supply and minimize the risk to the environment. Key areas for more research are evaluation of the nutritional benefits of new crops, further investigation of the environmental impact, and development of better techniques to identify and track genetically engineered products. *J. Nutr.* 132: 1384–1390, 2002.

KEY WORDS: • *food* • *agricultural* • *biotechnology* • *genetically modified*

Genetic engineering provides powerful tools to enhance the modification of plants to the potential benefit of society. However, as with any new scientific advancement, careful consideration of the effects of employing these tools is necessary to ensure that the result will be a net benefit to society. Recent controversies about genetically engineered crops have highlighted the need for experimental evidence and sound scientific judgment to assess the risks versus benefits. This debate was once relegated mainly to the plant scientists and activists and focused only on the food safety aspects. It has now flowed into the realm of the biomedical sciences with issues such as predicting allergenicity, assessing nutritional benefit, evaluating nutritional quality, meeting the nutritional needs of developing nations, and expanding the sustainable

food supply to meet future demands. Plant biologists and animal biologists often conduct their inquiries in parallel universes; interactions between the two fields of science are serendipitous and unsystematic. The Life Sciences Research Office held a forum during Experimental Biology 2001 to present current topics in food biotechnology to the experimental biology community with the hope of bridging the two universes. The conference had the further goal of identifying those areas in need of future research. This paper summarizes the benefits and risks of this new technology, describes consumers' knowledge and attitudes, explains the regulatory process new products of biotechnology go through prior to commercialization, and identifies challenges facing the industry, consumers and regulators.

Agricultural biotechnology may be defined as the use of living plant organisms, or parts thereof, to produce food and feed products such as insect-resistant corn, to develop processes like the manufacturing of biologics by tobacco, and to provide services such as, bioremediation of heavy metal contamination using genetically engineered poplars (1,2). Although biotechnology appears to be a new technology, the underlying concept is not new. Farmers have been using genetic manipulation to improve crops for thousands of years. For example, some 8000 years ago the Native Americans created corn by domestication of a wild plant called teosinte. Teosinte has a short, thin ear with very small kernels. The Native Americans used selective breeding, a crude form of genetic manipulation, in a remarkable way to produce a more

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productive variety. The end product looks very similar to the varieties of corn we produce today (3).

During the last century plant breeders expanded the tools of genetic manipulation beyond conventional cross breeding to use a variety of other breeding techniques, including embryo rescue, chemical mutagenesis, radiation mutagenesis, and somaclonal variation (4). These techniques do not allow control at the genome level; rather they allow multiple genes to transfer and require a rigorous selection process to ensure that the desired characteristic is stable (5). Plants created by these conventional phenotypic selection techniques do not undergo formal food or environmental safety evaluation prior to introduction into the environment and marketplace. On the other hand, over the past 20 years, the development of genetic engineering techniques now allows the development of crops containing specific single gene transfers. These are controllable, testable, and predictable changes, grounded on scientific principle. Genetically engineered crops undergo extensive testing of composition, safety, agronomic traits, and environmental effects prior to introduction into the marketplace. These assessments are described further in the section of this paper, entitled Regulation of Crop Biotechnology.

Benefits and concerns

Modifications of crop plants can be organized into two main categories: those that benefit the producer and those that benefit the consumer. Modifications that protect the crop from either biotic or abiotic stress or increase total crop yield benefit the producer and are called input traits. The majority of modified crops in commercial use fit in this group. Scientists have just begun to tap the large potential of biotechnology to produce varieties of plants that confer a wide spectrum of advantages to consumers. These varieties are modified with output traits.

One of the most publicized uses of biotechnology in agriculture is the modification of corn to express proteins produced by the common soil bacterium, *Bacillus thuringiensis* (Bt). Organic farmers have been using Bt as an insecticidal spray for over 40 y. Bt organisms have been modified to express a class of insecticidal proteins called Cry. These proteins are effective against certain insect pests but are harmless to humans, mammals and birds. Bt corn was introduced as a commercial crop in 1996 and has been described as "the most important technological advancement in insect pest management since the development of synthetic insecticides" because of its inherent resistance to infestation by one of the most serious corn pests, the European corn borer (*Ostrinia nubilalis*) (6).

In addition to decreasing yields, infestation of corn by the European corn borer facilitates spoilage by the mold, fusarium, which forms a mycotoxin, fumonisin, in corn (7). Fumonisin is a toxic substance that, among other things, has produced liver damage in all animals studied. Although currently inconclusive, some evidence suggests that it may also play a role in human esophageal cancer (8). Studies challenging maize hybrids with the European corn borer found decreased fumonisin concentrations for transgenic maize varieties expressing specific Cry proteins, 2.1 ug/g compared to 16.5 ug/g for non-transgenic maize hybrids (7).

Beyond the health benefit to livestock and consumers, infected corn becomes an economic problem. Corn that exceeds levels allowable for the intended use must either be discarded or used for another purpose, causing a loss of profit (9). In fact, overall losses to farmers as a result of the European corn borer-infested crops (including corn, cotton, sorghum, and other vegetables) total 1 billion dollars a year (10). On the

whole, Bt corn and Bt cotton have improved farm efficiency (11–13). A report by the U.S. Department of Agriculture concludes by saying that even though the benefit and performance of genetically modified crops varies depending on many factors including region and pest infestation levels, the adoption of crops such as Bt cotton in the Southwest and herbicide-tolerant soybeans led to significant increases in net yield, and a significant decrease in the application of insecticide (14).

An expansion of the same report by the Economic Research Service investigating same-year differences between average pesticide use of adopting and nonadopting farmers showed that those using genetically modified corn, soybeans and cotton combined used 7.6 million fewer acre-treatments (acres being treated multiplied by the number of treatments) of pesticides compared to nonadopters in 1997. In 1998 the difference increased to almost 17 million fewer acre-treatments by adopters (15).

On the other hand, others have concluded that despite a sharp increase in planting Bt corn, the percentage of corn treated with insecticides has remained constant throughout the period (6). Moreover, some research suggested that Bt corn pollen was harmful to the Monarch butterfly (16). Collaborative research by scientists from universities and research institutions in the US and Canada have concluded that potential risks of Bt corn to Monarchs is low. This is due to the density and time of pollen shed in relation to the period of larvae activity. Also, the proportion of milkweed plants growing near cornfields and the proportion of fields that are planted with Bt corn are other mitigating factors cited for the low risk to Monarch butterflies (17).

Other traits have been added to a variety of crops to defend from biological insults. Tomato, potato, squash and papaya are among a variety of crops that have been modified to resist infection by viruses or insect pests (18).

In addition to biotic stressors, plant productivity is influenced by abiotic factors such as herbicides, soil composition, water supply, and temperature. Therefore, conferring plants with genes that will help them withstand a wider range of environmental conditions could increase productivity. Plants are also being engineered to withstand drought, heat, cold temperatures and poor soil conditions such as salinity and aluminum contamination (19–23).

Increased total yield of harvest also can be achieved by enhancing efficiencies in the metabolic and photosynthetic pathways. Examples of pathways that could be improved to increase crop yield include nitrogen assimilation, starch biosynthesis, and modification of photosynthesis (24–26).

After harvest, time to market is an important economic factor due to the perishability of produce. Changing the rate of ripening would seem to be a benefit to both the farmer, by decreasing post harvest losses, and the consumer by increasing shelf life. To prevent delivering spoiled fruit, mature tomatoes are harvested while still green and ripened during delivery by exposure to ethylene, a ripening hormone in tomatoes. In 1994 the Food and Drug Administration approved a brand of tomato that had a genetic solution to this processing problem (27). The producers of the tomato used antisense technology to silence a gene that produces polygalacturonase, a pectin-degrading enzyme found in ripe tomatoes, thus slowing the ripening process (28).

Consumers stand to gain more than just produce with longer shelf lives. While still in its infancy, the technology is being used to produce plants that will have a whole range of output traits including increased nutritional value, medicinal properties, industrial utility, and novel taste and esthetic appeal. Many of our common food crops could be improved to

better meet the nutritional requirements of humans or animals. Protein, starch and oil composition and content as well as micronutrient content can all be improved to make foods and feeds more nutritious. (29–36) For example, a new strain of potatoes containing 30–60% more starch has been developed by inserting a bacterial gene for an enzyme in the starch biosynthetic pathway. These high-starch potatoes have less moisture and therefore absorb less fat during frying (37–39). Enzyme biotechnology also is being used to develop specialty oils containing more favorable fatty acid profiles such as high oleic acid peanut oil (40).

We have known for a long time that vitamins and minerals elicit biologic responses and have positive effects on health. Carotenoids are another class of nutrients that may be associated with decreased risk for certain cancers and macular degeneration. Among other plants they can be found in papaya (β -carotene), tomatoes (lycopene), kale and spinach (lutein) (29).

Beta-carotene has already been expressed in a genetically engineered rice cultivar, named Golden Rice, by addition of genes for three enzymes in the phytoene synthase pathway (two genes from a daffodil and one from the bacteria *Erwinia uredovora*) (41). This strain was also crossed with a high iron strain of rice to produce a strain with both qualities (42). Golden Rice has been the subject of much attention because it represents the potential of future biotechnology crops to benefit people in developing countries. This variety of rice could decrease malnutrition and blindness associated with vitamin A deficiency. However, there have been questions raised about the effectiveness of this rice because of the many biological, cultural and dietary barriers that must be overcome (43). These questions will need to be answered as the product is further developed prior to introduction.

Other phytonutrients with purported health benefits include glucosinolates, phytoestrogens, and phytosterols. Found in a wide variety of food sources, these compounds could selectively be overexpressed to therapeutic levels (44).

In a much different way, biotechnology is poised to completely change another aspect of preventative health care. Methods are being developed to produce vaccines in plants by introducing genes that express a protein antigen in crops such as corn, potatoes and bananas. When eaten these antigens elicit an immune response and have been shown to provide protection against a subsequent challenge from pathogens (45). The feasibility of this approach was demonstrated when mice fed transgenic Hepatitis B surface antigen expressed in potato tubers showed a primary immune response by producing antibody specific to the antigen (46). Companies are positioning themselves to become suppliers of a wide range of biotechnology products, including bioactive therapeutic proteins, blood proteins, animal health products, and industrial enzymes.

There are many other possible industrial applications for genetically modified organisms. For example, researchers at the University of Georgia engineered yellow poplar trees to have the ability to extract toxic ionic mercury from soil and convert the toxin to a relatively inert form. The gene was acquired from mercury-resistant bacteria that are soil-borne and thrive at sites polluted with heavy metals. In one study the engineered plants were capable of ten times the rate of mercury removal as compared to nonengineered plants (2). This is just one example of how phytoremediation, the use of plants to clean or contain contaminated areas, combined with biotechnology is a promisingly efficient, economical, and environmentally friendly technique that could restore soil health and revegetate contaminated waste sites.

Clearly, consumer preference is playing a role in the industry's choice of product development. Just as consumers have appreciated seedless oranges and watermelon, the industry is developing other fruiting crops that do not require fertilization to produce seedless fruit. Novel produce such as seedless tomatoes, squash, eggplant, peppers, strawberries, melons and cherries, to list a few of the possibilities, would be attractive to many consumers. Additionally, these fruits would have improved taste due to increased total soluble sugar compared to seeded fruit and may be of economic value to the processing industry as well (47).

Also in development is a sweet protein found naturally in the fruit of the African vine, *Pentadiplandra brazzeana*. This heat stable protein is 500 times as sweet as sucrose at higher concentration and as much as 2000 times as sweet in a two percent (by weight) solution. Lacking bitterness, it has a lot of potential as an alternative low energy sweetener (48).

It is clear that plant biotechnology has the potential to have a huge affect on tomorrow's society. Already over 50 biotechnology crop products have passed the regulatory review process and have been commercialized, ranging from corn and potatoes to tomatoes and squash (18). It is interesting to note that crops modified by biotechnology are the most rapidly adopted technology in the history of agriculture. In 1996 only 4.3 million acres of biotech crops had been planted; by 2000 that number increased to 109.2 million acres (49).

Public knowledge and attitudes

Although products derived from agricultural biotechnology are now common in the U.S. food supply, the topic does not appear to be an important issue to most U.S. consumers, and awareness remains moderate according to polls. Trends in consumer awareness and opinions about biotechnology and genetically engineered foods remain a shifting and somewhat controversial area. Polls designed to address similar issues at different times have found different results. Furthermore, such polls are sensitive to the wording and order of the questions. Perhaps the most telling information extracted from consumer polls are the trends over time, i.e., data obtained by asking the same questions after an intervening period of time. Notwithstanding the limitations of the technique, consumer polls remain an important tool in assessing public knowledge and opinion.

Evidently, most Americans are unaware of the extent to which crops derived from biotechnology have entered the marketplace. When consumers were asked how much processed food has genetically modified (GM) ingredients, only 14% responded with the correct answer (over 50% of processed foods have GM ingredients). Similarly, when asked whether or not they have eaten GM foods, 62% said no, they had not, while only 19% said that they had (50). With more than 60% of processed foods containing GM ingredients, it is highly probable that most people have eaten them at some time (51).

Even though consumer awareness of biotechnology is moderate, knowledge levels tend to be quite low. Nevertheless, more people are becoming aware of the issue. Between 1992 and 1996 only 34% of those asked said that they had heard either "a lot" or "something" about biotechnology. By 2000–2001 this number increased to 47% (52, 53).

Despite the controversy over the safety of eating GM foods, most American consumers seem to trust the food supply. When asked their willingness to buy GM potatoes or tomatoes protected from insect damage and requiring fewer pesticides, 74% in 1995 (53), and 70% in January of 2001 indicated they

were willing (52). It appears that the safety of eating foods derived from biotechnology is not on most people's minds. When asked an open-ended question regarding what they were most concerned about when it comes to food safety, the majority of consumers stated that they were worried about food handling, bacterial contamination, or pesticide residue issues. Very few people (2%) replied that they were concerned about biotechnology. In fact, when asked, "During the past few months, have you done *anything* or taken *any* action because of *any* concerns you may have about genetically modified foods?" only 5% of the respondents said "yes" (52).

There is still a great deal of confusion concerning the basic science of genetics and biotechnology. In a survey conducted in 1998, 45% of participants disagreed and one tenth agreed with the statement, "Ordinary tomatoes do not contain genes, while genetically modified ones do." In addition, when presented with the statement, "By eating a genetically modified fruit, a person's genes could also be changed" only 61% disagreed and 9% agreed (54). Educating the public on these matters might prove to be a challenge as well. When asked of their trust in biotechnology information sources, 41% stated that they trusted the American Medical Association, 32% said they trusted the Food and Drug Administration, and 4% stated that they trusted activist groups to provide them with truthful information about biotechnology (53).

Based on perceived consumer concerns, Gerber, Heinz and Frito Lay have made the decision to avoid ingredients that were derived from GM crops (55). In fact, JR Simplot Co, a supplier of potatoes to fast-food chains, says virtually all its customers don't want GM potatoes (56). Nevertheless, most food companies are not avoiding GM ingredients for domestic production, and by one estimate 60% of processed foods contain at least one GM ingredient (e.g., GM soy or corn flour; 51).

Consumer interest is but one of many factors that influences the use of these ingredients in the production, processing, manufacture and distribution of foods and food products. Industry is concerned over the capability and costs to deliver identity-preserved ingredients, the adequacy of testing methodologies for GM constituents, uncertainties in forecasting supply needs, and increased costs due to shortages of available non-GM ingredients. Safety does not appear to be a significant concern because producers and manufacturers rely on the regulatory system in place to ensure the safety of GM products.

Regulation of plant biotechnology

The regulatory process for the use of any technology should take into account both the risks and benefits of implementing that technology as well as the consequences of nonimplementation and the viability of alternative technologies. Biotechnology poses unique challenges to the regulatory process because it is a new tool with the potential to affect a wide spectrum of changes in an equally wide range of products. Therefore, each use of the technology must be reviewed on a case-by-case basis. Blanket acceptance or rejection of this technology will take years of practical experience.

Four federal entities play different roles in the current process, the National Institutes of Health (NIH), the Animal Plant Health Inspection Service (APHIS) of the USDA, the Food and Drug Administration (FDA), and the Environmental Protection Agency (EPA). The combination of the regulatory protocols provides coverage over all aspects of plant biotechnology from the laboratory to the farm to the marketplace.

The first step in making a product is at the laboratory

research level. The NIH has published a set of guidelines to specify practices for working with recombinant DNA and organisms and viruses containing recombinant DNA to promote a high level of biosafety. The NIH Guidelines for Research Involving Recombinant DNA Molecules cover all aspects of recombinant DNA research and require compliance from any institution that receives funds from the NIH. These guidelines are widely accepted and followed, even by institutions that do not receive NIH funding. Under the guidelines, institutions that conduct this type of research must set up an Institution Biosafety Committee (IBC) that is composed of experts in various fields relating to the subject matter and are encouraged to open their meetings to the public. The IBC is responsible for all the guidelines set forth by the NIH and must approve a project either before or during initiation, depending of the nature of the project and is keenly aware of pathogenicity and containment issues (57).

According to the Federal Plant Protection Act (FPPA), any transgenic crop containing DNA of a known plant pest is viewed as a potential plant pest and is therefore under the regulatory control of the APHIS Plant Protection and Quarantine within the USDA (58). Crop developers must file a notification for permission to import, grow, or move through state lines any genetically engineered plants. Developers must meet several criteria for APHIS to accept the notification. The species of the crop must already be considered safe for growth. The introduced genetic material must be stable. The function of the new genetic material must be known, and its expression in the regulated article cannot result in plant disease, produce products intended for pharmaceutical use, produce an infectious entity, or be toxic to a nontarget organism. In addition, the added sequence cannot pose a risk of creating any new viruses or be derived from any animal or human pathogen (59). If approved, the organism can only be grown with proper containment for data collection purposes and must be destroyed afterwards. After the developer has collected sufficient data, APHIS accepts petitions to deregulate the crop. Public input is invited at this stage. If found genetically stable and there is no finding of environmental concerns, the USDA grants a permit and no longer regulates the crop (58).

Mandated by the Federal Food, Drug, and Cosmetic Act (FFDCA) and the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA is the regulatory agency ensuring the health and environmental safety of all pesticides. Therefore, the EPA becomes involved in the review of biotechnology-derived crops when they are altered to produce a pesticide (plant-incorporated protectant or PIP). To register PIPs for commercial use with the EPA, the developer must submit an extensive amount of data concerning the toxicity, biodegradability, environmental effect, and effects on nontarget organisms. The EPA Office of Pesticide Programs grants an Experimental Use Permit allowing for planting in order to conduct field trials for the purpose of collecting the Agency's required data. Public comment is invited throughout each stage of this process via publication in the Federal Register. Under FIFRA, the EPA must review all data concerning the ecological, human, and animal health effects from the use of the PIP to certify that there will be no unreasonable adverse human or ecological effects. In addition, under the Food Quality Protection Act (FQPA), EPA must set safe tolerances for PIPs in foods for human consumption. It is then the role of the FDA to enforce the tolerance level in foods postproduction. The EPA may grant an exemption from a tolerance if there are extensive data on the safety of the introduced trait (60).

The FDA's mission, among other things, is to protect public health by ensuring the safety of foods. The FDA currently does

not have a mandatory premarket approval system in place for food products derived from biotechnology because it does not consider *the method of production* to raise significant safety issues. Rather, the FDA treats a food developed via biotechnology like other new foods and bases the safety assessment on the premise that a new food should be “as safe as” the food from which it was developed. The principles of safety assessment were published in the FDA’s 1992 policy statement, *Foods Derived From New Plant Varieties* (61).

The FDA concluded that it is sensible for developers of new varieties of foods to consult with the FDA so that “relevant scientific, safety, and regulatory issues are resolved prior to the introduction of such products into the marketplace”. To facilitate this consultation process, the Biotechnology Evaluation Team (BET) was created by the FDA’s Center for Food Safety and Applied Nutrition (CFSAN), Office of Surveillance and Compliance (OSC), and Center for Veterinary Medicine (CVM). The BET is composed of a consumer safety officer, molecular biologist, chemist, environmental scientist, toxicologist, nutritionist, and may include supplemental expertise depending on the product in question. The BET requests information, such as intended uses of the food, source of genetic material, intended technical affect of the modification, the expected effect of the composition of the food, the identity, function, and concentration of all newly expressed products, any known or suspected allergens or toxins, a comparison of the composition of the new food to that of the parental variety, and any other relevant information concerning the safety and nutritional assessment of the bioengineered food (62). Developing this information can require several years.

Although the FDA’s premarket review process has been voluntary, every company that has commercialized a new product developed via biotechnology has submitted its data to FDA for review, a process that can take several years. The FDA recently proposed making this premarket notification process mandatory and is currently receiving comments on the matter (63).

Throughout the food regulatory system the goal is minimizing risks by ensuring that a new technology or product is “as safe as” a similar product before it. Consequently the assessments are always comparative (61). A hazard is a hypothetical event that might do harm, and a risk is a hazard that actually occurs at some known frequency or probability. Food safety is achieved by risk identification, comprehensive hazard analysis, assessment, concluding that benefits outweigh costs, development of a risk management plan, and effective training and risk communication. Using all of these elements in a food safety evaluation maintains a precautionary approach.

Foods derived from biotechnology are more heavily regulated than any other new foods. Only new food additives and food ingredients are subjected to premarket approval—new nongenetically modified whole foods are not—and there is no required premarket screening of whole foods for toxicity or allergenicity.

Aspects of our food supply that may pose health risks include food borne illness, untested natural foods, dietary supplements, and dietary inadequacies such as over-nutrition, under-nutrition, and nutrition inadequacy. There are natural toxicants, allergies to various foods, chance additives, pesticide and herbicide residues, food ingredients and additives. Biotechnology carries a relatively low risk to human health and, in fact may become part of the solution to some of the problems mentioned above.

Consumers need to realize that there is extensive safety assessment and regulatory evaluation done on these products before commercialization. However, a fundamental difference

in opinion that is driving controversy needs to be resolved: Are transgenics inherently more or less safe? For this we need additional scientific evidence and critical thinking that would lead to science-driven policy decisions. We should learn to view safety as a comparative finding, where the safety of a product from biotechnology is determined in relation to the safety of the parent product.

Scientists and regulators need to build trust and credibility with consumers without using the “trust me” approach and should strive to be better educators because of the many challenges ahead in terms of acceptance for this technology.

Challenges for industry, regulators and consumers

New technologies take time for acceptance. For crop biotechnology, key factors hindering acceptance are the public’s limited understanding of modern agricultural practices and the science involved in biotechnology. Food, an emotional and personal topic, combined with misunderstanding of biotechnology, sensationalized media coverage, and complex ethical and social matters have combined to generate fear in some consumers. Well-organized protest groups will likely continue to center the public debate on issues of uncertainty and mistrust.

Yet biotechnology is becoming more and more a part of our lives. Genome sequencing, and analysis using new tools such as microarrays, allowing for very high throughput analysis of genes and gene expression patterns (64,65), are accelerating the discovery of genes with possible medical utility. Due to discovered homology in the human genome with that of other species, the use of nonhuman genes and proteins in human therapeutics will become more common. Revenues are expected to increase for biotechnology-modified crops in general, as a result of the production of crops containing “output traits.”

One of the biggest barriers facing the acceptance of this technology are European import restrictions. Antibio-technology sentiment is much stronger in Europe than in the U.S. European public support for applications of biotechnology that would protect crops from insects dropped from 58% in 1996 to 42% in 1999. Support for biotechnology-improved foods also dropped from 44% in 1996 to 31% in 1999 (53). There are many social and cultural reasons for this increase in opposition in Europe, including more sensational and negative media coverage, general support for small farms and open spaces, and a general opposition to foreign producers and their products. There are also political and economical reasons for greater opposition in Europe. Past food crises (e.g., BSE) have undermined confidence in government and exacerbated a general paranoia concerning the food supply. There has been limited educational outreach by the food industry, public leaders, academia or consumers. Antiglobalization sentiments and nontariff trade barriers have further complicated the issue.

Taken as a whole, the European situation is very complicated and unpredictable. However, many key leaders seem to want resolution, and as more products produced using this technology arrive on the market from around the world, there will be fewer alternatives. Consumer education could also be effective if led by European leaders and scientists. So far, the European Union has set out a plan for genetically modified food labels. It states that labels are required if any ingredient in a product contains more than 1% of GM material. Afraid that consumers view GM labels as a warning, European manufacturers are avoiding GM ingredients, thus eliminating choice at the market.

European consumers have expressed interest in identity

preservation of GM foods. Undeniably, identity preservation adds cost and complexity to the system. With so many different steps from seed to market, it would take countless measures to ensure proper labeling. This is further complicated by the fact that these genes may not be absolutely confined. For example, it is estimated that in 1999, 8% of Brazil's soybean crop was GM varieties, even though Brazil had not yet officially approved their use (66). In addition, the government of Mexico recently announced that it had found genes engineered in corn among native maize varieties even though genetically modified corn seed has not been approved for sale in Mexico (67). More recent studies have not been able to confirm these findings (68).

Even though raw or minimally processed foods may be tested with sufficient accuracy, there is no consensus as to what method of testing should be utilized so that quantitative assessments between different laboratories may vary greatly. In addition, with increasing processing, the amount of false positives and false negatives increases due to denaturation of molecules being tested. Therefore, effective identity preservation is currently not achievable. To maintain accurate identity preservation, more sophisticated testing methods will have to be developed and the process must become standardized (69).

If a large enough market exists for non-GM foods, the food industry will respond. Consumers will likely have to pay more for GM-free foods, and truthful and nonmisleading labeling language will need to be defined by FDA. Organic foods could become the market channel for these GM-free foods. In any case, the next generation of GM crops might require identity preservation to capture value for farmers and processors.

Consumer education also plays a large role in this whole debate. The study sponsored by the Pew Initiative for Food and Biotechnology in January of 2001 found that the percentage of consumers who thought GM foods are safe increased from 29% to 48% after being informed that more than half of the products available at the grocery store include genetically modified foods. It is clear that agricultural biotechnology is now at a critical juncture, and ongoing educational efforts will need to be expanded both for opinion leaders and consumers. Media coverage will most surely grow on this subject as more products are introduced into the marketplace, but efforts are needed to ensure that the coverage is balanced. Ideally, the criteria most consumers will continue to use when selecting food will be taste, value, nutrition, safety and convenience instead of fear and emotion. If properly developed, agricultural biotechnology represents an opportunity for developing countries to realize tangible health and nutritional benefits with sustainable agriculture and new market niches. In fact, China and India are actively developing this technology, and their support for biotechnology may turn the tide in global public acceptance.

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