

**VIEWPOINT****Application of Modern Biotechnology to Food and Agriculture: Food Systems Perspective**

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**ABSTRACT**

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The purpose of this article is to provide nutrition educators with an introduction to a range of considerations and forces that are driving the application of modern biotechnology in the food and fiber sector based on a food systems perspective. In doing so, the following issues are critically assessed: (1) the global debate on how to regulate genetically engineered (GE) foods and crops, (2) cultural differences in public perceptions of GE foods, and (3) evaluation of selected GE traits against the principles of social, economic, and ecological sustainability, including the potential of modern agricultural biotechnology to enhance global food security. Where appropriate, we also review other agricultural technologies and the broader political, social, and economic contexts in which these technologies have been introduced. Finally, we offer recommendations for how multiple stakeholder groups, including policy makers, biotechnology advocates, and nutrition educators, can move toward a more informed dialogue and debate on this issue.

**KEYWORDS**

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modern biotechnology, food and agriculture, food systems perspective

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**INTRODUCTION**

The Convention on Biological Diversity (CBD) has defined biotechnology as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." Interpreted in this broad sense, biotechnology covers many contemporary agricultural and food manufacturing tools. However, when biotechnology is used in a more narrow sense, it refers only to new deoxyribonucleic acid (DNA) techniques, molecular biology, and reproductive technological applications ranging from gene transfer to DNA typing to cloning of plants and animals. Whereas there is little controversy about many aspects of biotechnology and its application, there has been considerable controversy about the use of modern biotechnology in food and agriculture, particularly the use of genetic engineering and genetically engineered organisms (GEOs).

Genetically engineered (GE) crops were first introduced for commercial production in 1996. Since then, their use has increased rapidly. In 2002, GE crops were planted on 145 million acres worldwide. The earliest applications of genetic engineering to agriculture have focused primarily on simplifying pest management in widely planted crops. Technology targets have been chosen by the private sector based

on two factors: what the tools of genetic engineering could feasibly accomplish and potential market size and profitability. One major category includes crops engineered for disease and insect resistance to prevent crop losses (eg, insect-resistant corn and cotton), and the second category encompasses herbicide-tolerant (HT) crops (eg, glyphosate-resistant, or Roundup Ready [RR] soybeans [Monsanto Co, St. Louis, MO]), which allow farmers to spray broad-spectrum herbicides over growing crops. During the period from 1996 until 2002, the dominant trait used has been herbicide tolerance, which now occupies 75% of the total acres planted globally. *Bacillus thuringiensis* ( *Bt* ) crops (engineered for insect resistance) occupy 17% of the total acres planted globally. In 2002, 3 countries accounted for 95% of the total area (total number of acres) of GE crops planted globally: the United States (66%), Argentina (23%), and Canada (6%). The principal GE crops grown were soybeans, corn, and cotton.

The purpose of this commentary is to provide nutrition educators with an introduction to a range of considerations and forces driving the evolution of the application of modern biotechnology in the food and fiber sector based on a food systems perspective. The Figure

Figure. Conceptualization of the interrelated components of local food systems.

depicts the interrelated components of local food systems, which include the production, processing, distribution, access, use, and recycling/ composting of food. These interrelated components are influenced by (1) natural resource allocation, (2) use of technological systems, and (3) society and culture (eg, values and beliefs, cultural norms, food practices), which are, in turn, influenced by broader forces, including governing institutions and public policies. Here we critically assess the following issues from a food systems perspective: (1) the global debate on how to regulate GE foods and crops, (2) cultural differences in public perceptions of GE foods, and (3) an evaluation of selected GE traits against the principles of social, economic, and ecological sustainability, including the potential of GE crops and modern biotechnology to enhance global food security. Where appropriate, we review other agricultural technologies and the broader contexts in which these technologies have been introduced. Finally, we offer recommendations for how policy makers, biotechnology advocates, and nutrition educators can move toward a more informed dialogue on this issue.

## GLOBAL DEBATE: HOW TO REGULATE GE FOODS AND CROPS

In the United States, three federal agencies regulate different aspects of GE foods: the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and the Department of Agriculture (USDA). These agencies operate under separate statutes and are overseen by different committees of Congress. They coordinate their efforts under the 1986 Coordinated Biotechnology Framework. The Table

Table. US and Selected International Agencies with Legal Authority in Regulating Genetically Engineered (GE) Plants and GE Organisms\*

Agency	Authority	Specific Regulations	Responsibility
White House	Executive	1986 Coordinated Framework	Coordination of federal activities
US Department of Agriculture	Plant Protection Act	7 CFR 340	New pests, environmental impact
US Environmental	Federal Food, Drug, and	FFDCA rules, FIFRA rules	Plant incorporated protectants

Protection Agency	Cosmetic Act (FFDCA), Federal Insecticide, Fungicide, Rodenticide Act (FIFRA)		(health and environmental risks)
US Food and Drug Administration	FFDCA	1992 Statement of policy	Whole foods, risk to human health
European Union	European Community (EC) treaty	Directive 2001/18/EC	Environmental risks
European Union	EC treaty	EC 258/97, EC 1139/98, EC 49/2000, EC 50/2000, Directive 2001/18/EC	Food risks and labeling <sup>†</sup>
United Nations	Convention on Biological Biodiversity	Cartagena Protocol on Biosafety	Interboundary movement of living modified organisms (LDMs) ‡
Codex Alimentarius Commission	Food and Agriculture Organization and World Health Organization	In process	Labeling, human health

\*Adapted from Bucchini L, Goldman LR.<sup>12</sup>

<sup>†</sup>In July 2003, the European Parliament approved legislation that will require strict labels for food and feed made with genetically engineered (GE)

ingredients. Under the new rules, all GE products including animal feed, vegetable oils, seeds, and byproducts containing more than 0.9 percent GE

material will have to be labeled. The legislation also ensures that GE foods are traced from their point of origin to the supermarket. The new laws are

expected to take effect in early 2004.

<sup>‡</sup> Living modified organisms (LMOs) is language that is used in this context to refer to genetically engineered organisms.

highlights the US agencies and selected international entities with legal authority to regulate GE plants

and GEOs. In the United States, risk assessment requires the agency to analyze and interpret the scientific data and make informed predictions about the risks imposed by an activity. After assessing risk, risk management requires that the agency make legal and policy judgments about how to employ regulatory options that are available to the agency under its governing statute. Policy debates surrounding GE foods and crops are not only in the scientific and administrative communities but also increasingly with the public, which is showing a wariness of the technology. For example, focus groups commissioned by the FDA revealed that the majority of participants were surprised and outraged to learn that GE foods were on the market without their knowledge. The global debate on how to regulate GE foods, crops, and GEOs encompasses a multitude of issues: (1) food safety risks, (2) environmental risks, (3) use of the precautionary principle for dealing with scientific uncertainty, (4) who participates in risk analysis and risk decision making, and (5) labeling and consumer right to know issues, each of which is described below in more detail.

## **Food Safety**

In 1992, the FDA adopted a regulatory policy that specified that foods produced through genetic engineering techniques or containing GE substances substantially similar in "structure, function, and composition" to substances already in the food supply (proteins, carbohydrates, fats, and oils) were to be considered "generally recognized as safe". This terminology was later changed to "substantially equivalent". Under current FDA regulatory policy, if foods produced through GE techniques are deemed generally recognized as safe or substantially equivalent, they are not required to undergo mandatory premarket approval or premarket testing. The 1992 policy was opposed by FDA's own scientists, as was shown in documents that were forced to be released during a 1998 lawsuit against the FDA charging failure to fulfill its regulatory duties. In January 2001, the FDA proposed modifications to its regulatory policy and called for a 120-day premarket notification for any bioengineered food that would be brought to market. However, to date, the previously proposed change in FDA regulatory policy has not yet been approved.

In January 2003, the nonprofit Center for Science in the Public Interest (CSPI) released a report concluding that the FDA's safety review process for the regulation of GE crops and foods needs to be strengthened to improve the quality of the FDA's regulatory oversight and to improve public confidence in the safety of foods made from these crops. Through examination of 14 submissions obtained under the Freedom of Information Act, CSPI found that when the FDA requested additional information to conduct a complete and thorough safety assessment, companies refused the FDA's request for more information 50% of the time (3 of 6). According to the CSPI report, several biotechnology companies declined to provide requested scientific data to the FDA about strains of GE insect-resistant corn. The report revealed technical shortcomings in data provided by the companies and errors that the FDA failed to detect. It also was noted that inadequacies in the FDA's review process will be exacerbated when more complex changes are made in the metabolism of plants and a wider range of genes are used.

To address the observed shortcomings in the FDA's current regulatory policy, CSPI recommended that Congress provide the FDA with legal authority for mandatory review and safety approval of GE crops, including the authority to require any data it deems necessary to conduct a thorough food safety assessment. CSPI also has recommended that the FDA (1) develop detailed safety standards and testing guidelines; (2) require developers to submit complete details about their testing methods and the actual data from safety tests, including statistical analyses of those data; (3) establish an approval process that is transparent and provides the public with an opportunity to comment on submissions; (4) perform and make available to the public detailed assessments of commercialized GE crops; (5) reassess the safety of commercialized GE crops if new safety concerns are recognized or new tests become available; and (6) ask developers of current GE crops to provide additional data to give greater assurance of safety than the summary data previously provided to the agency. Finally, CSPI has recommended that when the FDA

lacks the authority to implement some of these recommendations, Congress should pass new legislation.

Significant progress toward a global consensus on how to regulate the safety of GE foods was made when the Codex Alimentarius Ad Hoc Task Force on Foods Derived from Biotechnology completed draft principles for the human health risk analysis for GE foods. The draft principles stated that all GE foods should include a premarket safety assessment on a case-by-case basis for both intended and unintended effects and that all countries should include risk management measures, including a system for postmarket monitoring for the purpose of facilitating withdrawal of products from the market when a risk to human health was identified. These guidelines were adopted by the Codex Alimentarius in July 2003. This is considered a critical development globally because the World Trade Organization (WTO) considers the standards of the Codex Alimentarius Commission to be the global science-based standard, and, thus, immune to international trade challenges.

### **Environmental Risks**

The EPA is the federal agency that evaluates and licenses pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). For plant-incorporated protectants, for example, GE crops with insecticidal properties, the scrutiny of the EPA encompasses environmental risks and human health concerns, although it is limited to pesticidal substances (the inserted DNA and the protein it produces). The USDA, under the Plant Protection Act, regulates all GE plants that have pest potential (see Table). A report issued by The National Research Council (NRC) on the environmental effects of transgenic plants has concluded that the USDA needs to (1) more rigorously review GE crops before approving them for commercial issue, (2) more actively seek outside scientific peer review of crop applications and advice on changes in regulatory policy, (3) more actively solicit public comment, and (4) monitor transgenic crops more closely after their approval. In another recent NRC report entitled *Animal Biotechnology: Science-Based Concerns*, it was noted that for some applications of transgenic (GE) animals, scientific uncertainty will be a particular concern owing to the novelty of the health and environmental questions posed and the lack of established scientific methods for answering them.

At the international level, controversy has stemmed from whether the Cartagena Protocol on Biosafety, commissioned by article 19 of the 1992 CBD, is needed to regulate living modified organisms (LMOs) that are introduced into the environment. This international treaty, which is based on the precautionary principle, gives countries the right to bar imports of GE seeds, microbes, animals, and crops seen as a threat to their environment. Under what is known as the Advance Informed Agreement (AIA) procedure, any Party shipping LMOs for intentional introduction into the environment for the first time shall have to give prior notification to the importing country that is a party to the Protocol and provide sufficient information to enable it to make an informed decision. LMOs intended for food, feed, and processing are subject to information sharing requirements through a central Biosafety Clearinghouse. Countries can also decide whether or not to import these commodities based on their own scientific risk assessment. Finally, exporters must ensure that all shipments are accompanied by appropriate documentation that is required under the Protocol. The Cartagena Protocol, which was approved by over 130 countries in January 2000, became legally binding to its signatories in September 2003, 90 days after it was ratified by 50 countries. Although the United States has not ratified the protocol, it must adhere to its provisions when shipping GE products to countries that are signatories to the protocol.

### **The Precautionary Principle as a Basis for Dealing with Scientific Uncertainty**

The precautionary principle has its origins in the German word *Vorsorgeprinzip*, which is freely translated as the obligation to "foresee and forestall" environmental harms. The precautionary principle was established as a concept of environmental law in the 1970s. Since that time, it has been invoked in

numerous international treaties, including the Rio Declaration on Environment and Development, the Bamako Convention on Hazardous Waste in Africa, the Convention on Biological Diversity, and the Stockholm Convention on Persistent Organic Pollutants. A 1998 consensus statement characterized the precautionary principle in this way: "when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established." The 4 central components necessary to achieve its implementation include (1) taking preventive action in the face of uncertainty, (2) shifting the burden of proof to the proponents of an activity, (3) exploring a wide range of alternatives to possibly harmful actions, and (4) increasing public participation in decision making. As noted by Applegate, "properly construed, this principle defines a process for taking environment- and health-protective actions while the dangers of not taking such protective action remain uncertain.... It seeks to anticipate the risks of new and existing technologies so as to avoid or minimize them." In December 2002, the British Medical Association (BMA) issued a statement on GE foods in which it reiterated its support for the precautionary principle.

Adherence to the precautionary principle is consistent with at least 3 different tenets of scientific analysis. First, it fits with the desire to minimize type II error (false-negative). Scientists in the fields of ecology, conservation biology, and natural resources management have been increasingly concerned about the tendency to downplay type II error in studies that aim to inform environmental policy. As explained by Kapuscinski,

*this is because the potential for harm is greater if conclusions commit a Type II error (false negative) compared to a Type I error (false positive) since recovery from most harm to ecosystems or human health involve large time lags, and are sometimes irreversible. Type I errors, on the other hand, are usually limited to short-term economic costs borne by the developers and marketers of GEOs.*

Second, the precautionary principle assists in accounting for another type of uncertainty that arises from ecological systems research, something that is inherent in all biological systems. With regard to the release of GEOs into the environment, uncertainty arises from gaps in current knowledge about the behavior of a GEO, the novel traits modified, variability in the environment, and limits in predicting the evolution of GEOs subsequent to their release in the environment. Third, by broadening participation in the risk characterization process, the precautionary principle may be helpful in reducing type III error, which occurs when scientists provide an accurate answer to the wrong problem, that is, they ask the wrong question. A realistic way to cope with such inherent uncertainty in complex biological systems is to implement an adaptive management approach to biosafety governance. Such an approach for assessing the ecological and human health effects for the release of GEOs into the environment that is consistent with the CBD adherence to the precautionary principle has been developed by the Scientists' Working Group on Biosafety.

It should be acknowledged that the precautionary principle has been criticized by some as being overly vague. Other criticisms of the precautionary principle include (1) current regulatory processes are already precautionary, (2) the precautionary principle is not scientifically sound because it advocates making decisions without adequate scientific justification, and (3) if it were implemented, the precautionary principle would stifle innovation by requiring proof of safety before new technologies could be introduced. However, a recent analysis has concluded that implementing the precautionary principle is not only good science, it is also good economics for at least 4 reasons: (1) precautionary action benefits workers, (2) precautionary action does not impose damaging costs on industry, (3) precautionary policies can stimulate technological innovation, and (4) economic logic supports timely action to avoid substantial health and environmental costs.

### **Who Participates in Risk Analysis and Risk Decision Making?**

Another controversy surrounding the development and use of GE foods and crops is who participates in risk analysis and the risk decision-making process. Risk analysis is the integration of science-based risk assessment with inputs from public policy, which integrates science into a wider context of social, cultural, political, and economic determinants. Whereas risk assessment is a highly formalized and detailed process that is carried out by technical experts, risk analysis is characterized as an analytic-deliberative process that seeks input from stakeholders regarding how uncertainty should be addressed. The rationale and importance of engaging in risk analysis have been summarized by Auberson-Huang:

*Opening the dialogue between precaution and risk with civil society is a move towards a systems approach, where all variables are admitted simultaneously for the characterization, framing, management, and communication of risks. A dialogue between precaution and risk is a dialogue between science and society.*

In the risk analysis process, good science is considered necessary and indispensable but not sufficient for good risk characterization because risk decisions are ultimately public policy choices. On a societal level, use of a risk analysis approach to inform public policy making could be achieved through use of various deliberative processes: expert panels, citizen juries, stakeholder decision analysis, and deliberative polling. And while participatory approaches to risk analysis and risk decision-making have been used in various parts of the world, for example, Denmark, Norway, the United Kingdom, and Japan, their use in the United States has been limited.

In 1996, the NRC Committee on Risk Characterization released a report in which it recommended that federal agencies incorporate iterative interaction between technical analysis and social deliberation when developing health, safety, and environmental regulations. In this framework, there are 3 rationales for including broad participation in risk characterization: normative, substantive, and instrumental.

*Normative rationale* is that governments should obtain the consent of the governed and that citizens have a right to participate meaningfully in public decision making and to be informed about the bases for government decisions. *Substantive rationale* is that participation by people with diverse experiences will provide key information and insights to risk analysis. *Instrumental rationale* is the premise that broad participation enhances the chances of reducing conflict and increases acceptance and trust in risk decisions made by governments and international bodies. Crucial to this framework is the recursive interplay between analysis and deliberation in reaching some degree of agreement among scientists, governments, and affected and interested social groups over the risks that should be treated as possible hazards. The Scientists' Working Group on Biosafety and the biotechnology "Safety First Initiative," that is, a public-private partnership formed to facilitate the transparent development of proactive safety standards that anticipate and resolve safety issues as far upstream as possible, are two examples of recent projects that have used the NRC risk characterization process to assess the environmental and human health effects of GEOs.

### **Labeling and the Consumer Right to Know**

Labeling issues span science, public policy, consumer education, and consumer right to know issues. Currently, the FDA does not require labeling of foods derived from bioengineering because it believes that the process used in producing a crop or food is irrelevant as long as the nutritional content remains the same as its nonbioengineered counterpart. In 2001, the FDA proposed guidance to the food industry for voluntary labeling of GE foods. However, without stricter government regulations regarding cross-contamination of GE and non-GE crops, the FDA's guidance is of little value, and food labels such as "biotech free" may prove to be misleading. Also misleading, according to the FDA, is the fact that such phrases could imply that nonbioengineered food is superior to bioengineered food. Hence, the FDA's proposed labeling guidance shifts the burden of responsibility from the companies developing and marketing GE foods onto producers and companies marketing the product, which are typically those

marketing organic foods. In the end, individuals who wish to purchase foods without bioengineered ingredients must purchase the more expensive certified organic alternative.

Representative Kucinich (D-OH), who introduced national level legislation to require GE food labeling, first in 1999 and then again in 2002, believes that labeling GE foods is warranted because of the widespread use of genetic engineering in US food production, despite a limited history of use. Confirming this belief are groups such as the BMA, which noted that labeling GE foods could be helpful in tracing any potential health problems should they occur. Zepeda et al reported that the presence of labels on GE foods could reduce consumers' risk perceptions by transforming the perception of risk from one that is involuntary to one that is voluntary. Recent research on consumers' risk perceptions toward GE soybeans found that participants wanted GE foods to be labeled even when they provided consumers with a demonstrated benefit. Many large multinational food companies have established processes that keep GE products separate from non-GE products, particularly if they ship products into the European Union and Japan because these countries already require segregation for labeling purposes. Segregation has been made possible by the use of identity preservation techniques that keep harvested GE crops separate from the point of planting to the point of food processing and, finally, to the point of export. Although not infallible, identity preservation products can be tested to ensure that cross-contamination of products has not occurred at some point in the supply chain. Many countries, including member countries of the European Union, Japan, Australia, New Zealand, South Korea, and China, already require GE products to be labeled. Other countries, such as Saudi Arabia and Taiwan, will be implementing mandatory labeling requirements in the near future.

As the GE labeling debate continues around the globe, consumer right to know acts are surfacing in the United States as an alternative. Trying to respond to consumer demands without unnecessarily burdening GE food producers and processors, the proposed scheme would require simple disclosure. Basically, the act would require registration of all GE food products with a state agency that would maintain a database accessible to consumers. Enforcement mechanisms, administrative and judicial procedures, liabilities, and available defense mechanisms would be included in the act. Advocates of this route believe that this compromise meets the consumer's need to know but does not jeopardize the cost or sales of GE products. Finally, it is argued that a right to know act should be formulated to survive legal hurdles that have blocked state-level labeling legislation thus far.

## **CULTURAL DIFFERENCES IN PUBLIC PERCEPTIONS OF GE FOODS**

There have been very different reactions to GE foods in the United States compared with other parts of the world, particularly in Europe, and in many developing countries. Differences in public reactions to GE foods are largely the result of moral and ethical concerns that reflect the history, traditions, experiences, beliefs, and values of a diverse citizenship. Understanding such differences in underlying values can aid both US and international policy makers in disseminating information on agricultural biotechnology and GE foods to citizens and other stakeholders in the United States and abroad. Underlying cultural differences in public perceptions of GE foods stem from (1) differences in the cultural significance of food and food production, (2) differing perceptions of nature, (3) the level of trust in regulators, (4) perceptions of science, (5) the quality of citizen engagement, and (6) concern about threats to pluralism. Each of these is explored below in more detail.

### **Cultural Significance of Food**

One significant difference between Europeans and Americans regarding their attitudes surrounding GE foods relates to the relative cultural significance of food in the lives of Europeans versus Americans. Whereas American national identity is generally not linked to food and food production, the opposite is true in Europe, especially in countries such as France and Italy, where national identity is entwined with

particular varieties, quality, and preparations or purity of food. Consequently, the introduction of GE foods is perceived by many Europeans to be a threat to their cultural identity.

### **Perceptions of Nature**

There are different cultural and ethical notions between Europeans and Americans about what constitutes nature and how it is valued. Americans tend to equate nature with wild spaces--hence the practice of preserving large tracts of unsettled land as nature preserves. On the other hand, Europeans share more densely populated land and have access to fewer unaltered landscapes, so there is a broader sense of what counts as nature and what, therefore, should be protected or left unaltered. The importance of wildness also applies to animal welfare issues. In the United States, greater emphasis is placed on protecting wild or endangered animals rather than farm animals. In Europe, there is a broader public debate over issues of animal welfare, including animal husbandry practices.

### **Trust in Regulators**

Europe and the United States have very different histories of biotechnology regulation and different levels of public trust in government agencies. In a recent survey that evaluated Europeans' and Americans' perceptions of trust surrounding the regulation of biotechnology, Europeans reported placing the highest confidence in international organizations such as the United Nations and the World Health Organization. In contrast, in the United States, most support was reported for US government agencies, including the USDA and the FDA. In Europe, the ability of regulators to act impartially and quickly to protect public health with respect to food safety issues is viewed as deeply suspect. Much of this skepticism is the result of the experience with bovine spongiform encephalopathy (BSE) or "mad cow disease" in the United Kingdom and recent outbreaks of BSE in other countries in Western Europe.

### **Perceptions of Science**

US and European perceptions on the role of science in society also differ. In the United States, science is seen as a powerful and revered tool. Industry and government tend to rely heavily on scientific data to support or reject concerns articulated by other stakeholders. There is limited tolerance for scientific disagreement because such disagreement is interpreted as meaning that the truth has not been uncovered and that the science is simply not complete. In Europe, there appears to be an understanding that science is a process of debate or a debate in process. This means that it is possible to have legitimate disagreement by reputable scientists and conflicting scientific results. The power of science is, therefore, less absolute. Instead, it is considered a tool to be used in solving a problem. This understanding of the role of science as a process of debate permits a broader range of ethical, social, and cultural factors to be valued more highly in Europe compared to the United States.

There are additional cultural factors at play with respect to the role of science in the United States. First, obstacles to progress and scientific freedom are viewed unfavorably. In addition, a significant American sentiment is libertarian, that is, against government regulation or the intrusion of government into the affairs of individuals and private corporations. Thus, a belief in the power of science and a significant libertarian sentiment explain why the United States has insisted that science be halted only if there is "sound scientific evidence" to support public policy decisions. In Europe, there is less confidence placed in the power of science, which has led to the adoption of the precautionary principle as being the dominant standard for progress in the face of scientific uncertainty.

### **Quality of Citizen Engagement**

In addition to cultural differences, the quality of citizen engagement on GE foods has differed in the European Union and the United States. Whereas Americans are most often addressed in their capacity as consumers, Europeans often separate their roles in society into citizens first and consumers second. Countries such as Denmark have a tradition of successful, in-depth citizen engagement on public issues that are perceived to have profound societal effects, including GE foods. These methods of citizen engagement have not been widely explored in the United States, where a dominant philosophy is to rely instead on market regulation, which focuses primarily on allowing individuals to make their value preferences known at the cash register.

### **Concern about Threats to Pluralism**

With the rise of global markets, the establishment of the WTO, and the increased concentration in power by multinational corporations, many Europeans and citizens of developing countries believe that corporate consolidation in the agricultural food system, including the biotechnology sector, poses a threat to the values of pluralism. A first point of concern is that the trade context in which international discussions on modern agricultural biotechnology occur permits economic and scientific values to be raised almost entirely to the exclusion of other social, cultural, and ethical values. Concerns have also been expressed that the WTO Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement, which places primacy on the respect for intellectual property rights over other values, will primarily benefit industrialized countries over the welfare of developing countries that serve as stewards to the vast majority of the world's genetic resources. Consequently, the following issues have been implicated in the backlash against the use of modern biotechnology: the morality of bioprospecting, reductions in the world's biodiversity, the destruction of agrarian traditions, cultivating economic dependence on multinational corporations, access to benefits, and global justice.

Peasant farmer and indigenous peoples' organizations have expressed concern that developments in modern biotechnology, along with the development of the International Union for the Protection of New Plant Varieties (UPOV), could threaten their food sovereignty, which they believe is a prerequisite to achieving food security. Food sovereignty is the right of peoples to define their own policies and strategies for sustainable production, distribution, and consumption of food with respect for their own cultures and own systems of management of natural resources and rural areas. It is a term that was coined by Vía Campesina -- an international association of small farmers and peasants from around the globe. A key focus of the food sovereignty movement is strengthening people's political power by working with disadvantaged groups from around the world, including women, to build their organization, negotiation, and advocacy skills. Similarly, the Organization for African Unity (OAU), now the African Union, has developed a model law for the regulation of (1) access to biological resources, (2) community rights, (3) farmers' rights, and (4) plant breeders' rights. The most crucial features include the belief that breeders' rights are subordinate to farmers' rights, the belief that patent protection of any life form is prohibited, and strong support for the role of women. Although the OAU model law is based in provisions of international law (the CBD), it has recently come under challenge from the World Intellectual Property Organization, an organization whose mandate is to promote and protect intellectual property rights (ie, to enforce patent rights) and uphold the UPOV. How such developments will continue to unfold in the future is uncertain.

### **ECONOMIC, SOCIAL, AND ECOLOGICAL SUSTAINABILITY**

When assessing individual applications of GE to food and agriculture from a food systems perspective, it is important to evaluate their characteristics according to the adherence to the principles of economic, social, and ecological sustainability. Sustainability is defined as "society's ability to shape its economic and social systems so as to maintain both natural resources and human life." Because HT and insect-resistant crops collectively account for the majority of the GE crop acreage planted globally (92% of the

total acreage planted globally), these two applications are assessed with regard to their adherence to the interrelated principles of social, economic, and ecological sustainability. Other applications of modern biotechnology are evaluated in terms of their potential to enhance food security. Alternative technologies, including conventional plant breeding, as well as the broader contexts in which these technologies have been introduced, are also discussed.

## **Herbicide-Tolerant Crops**

HT GE crops, particularly RR soybeans, have been adopted rapidly in both the United States and Argentina. Farmers in these countries have embraced the technology because it greatly simplifies soybean weed management and provides additional flexibility in managing weeds. The faster and more extensive adoption of HT GE crops in Argentina, particularly RR soybeans, has been driven by greater economic advantages. First, farmers in Argentina have the unrestricted ability to save and replant seed. According to Qaim and Traxler, only about 30% of soybean seed is purchased annually in Argentina. Second, the seed premium for RR soybeans in Argentina is less than half the premium in the United States. In the United States, RR soybeans were an economic wash until 2001 because the increased cost of seed almost equaled the reduction in herbicide expenditures. Since 2001, the price of glyphosate has fallen dramatically, as have the prices of other soybean herbicides. These price changes have proven to be an economic windfall for soybean farmers. Although such benefits are indirectly linked to RR technology, these economic benefits do not stem from inherent efficiencies or benefits of the technology itself but rather have arisen from competitive pressures and price changes in the marketplace.

As currently used in Argentina, HT GE crops (soybeans) have limited crop diversity by increasing soybean acreage. There are other externalized costs to use of HT GE crops that are also not considered. For example, RR soybeans have been shown to impair plant root development and the activity of microorganisms responsible for nitrogen fixation by soybean plants. Nitrogen fixation of soybeans is a major agronomic advantage of soybeans and is critical in achieving optimal yields while keeping fertilizer costs to a minimum. Under well-watered conditions and in soil with ample nitrogen available, depressed nitrogen fixation appears to have little impact on RR soybean yields. But in less fertile soils and/or under drought stress, yield losses reported with RR soybeans were up to 25% compared with those of controls.

The most substantial benefit of HT crop technology stems from its compatibility with no-till production systems. An updated study on the impacts of HT crop varieties estimated that most of the recent growth in no-till production systems in the United States has occurred as a result of the availability of HT GE crop varieties. Benefits of conservation and no-till systems include less erosion and sedimentation of waterways, improved soil quality, less fuel and labor use, and better wildlife habitat. A survey of soybean growers found that 1.8 fewer tillage passages were made, with most of the decrease attributed to RR soybeans. However, the report did not discuss the impact of RR soybeans on herbicide use, weed shifts, or the need to manage resistance. Most HT GE crops are resistant to glyphosate, a relatively high-dose herbicide; hence, the technology has not reduced herbicide use. Recent research has highlighted that once results are broken down by the type of herbicide used, an estimated 13.4 million pounds of glyphosate are substituted for 11.1 million pounds of other synthetic herbicides. Other research has demonstrated that slightly more pounds of herbicide are applied on the average acre of RR soybeans compared to the average acre planted in conventional varieties. Total herbicide use on RR soybean acres is gradually rising because of weed shifts, overabundant weed seedbanks, and the loss of susceptibility to glyphosate in some weed species. Problems with resistance and weed shifts are an adverse impact triggered by how HT technology is used and do not reflect an inherent flaw in the technology. Unfortunately, the way in which the technology has been used has resulted in an increased reliance on one weed management tool--herbicides--and an increased dependence on a single herbicide, glyphosate.

## **Insect-Resistant Crops**

*Bt* technology uses a natural plant toxin and a novel delivery system to mimic chemical-based pest management systems. Overall, the impact of *Bt* corn on insecticide use has been modest. Until *Bt* corn was commercialized, most growers did not treat for the European corn borer (ECB) and southwestern corn borer (SWCB) and accepted episodic damage, especially in the northern and eastern corn belts. In 1999, growers treated 8.1% of corn acres with an insecticide targeting the ECB and the SWCB, the highest percentage in the last decade. By 2001, when close to one quarter of corn acres were planted to *Bt*-expressing varieties, ECB and SWCB insecticide treatments had fallen to 6.9%, a modest drop. *Bt* cotton, on the other hand, has reduced insecticide use markedly in several states. Close to half of cotton insecticide treatments either solely or partially target the budworm-bollworm complex of insects, which is the target of *Bt* cotton. The average cotton acre received 2.21 acre treatments in 1992. Reliance peaked in 1995 at just over 3 acre treatments per planted acre and has fallen to 0.77 acre treatments per planted acre in 2000.

## **Are GE Crops Being Used to Achieve Sustainability?**

Lewis and coauthors argue that the central problem plaguing pest management has been the failure to recognize the need--and opportunities--to manage natural plant pest beneficial interactions and that any toxin-based intervention will be met by countermoves that neutralize their effectiveness. The reason for this has been explained in a seminal article published in the *Proceedings of the National Academy of Sciences*, which stated that

*Genetic engineering and other such technologies are powerful tools of great value in pest management. But, if their deployment is to be sustainable, they must be used in conjunction with a solid appreciation of multitrophic interactions and in ways that anticipate countermoves within systems. Otherwise, their effectiveness is prone to neutralization by resistance in the same manner as pesticides.*

Paradoxically, the best way to maximize the benefits of many technologies, including HT and insect-resistant GE crops, is to use them sparingly and in constantly changing combinations with other technologies. Unfortunately, this is not how either of these two applications of genetic engineering has been used to date, thereby limiting the long-term potential usefulness of the technology. Hubbell and Welsh have concluded that development of genetic traits with a higher potential for promoting a more sustainable agricultural food system have not been pursued owing to (1) a lack of regulatory policies that explicitly promote sustainable agriculture; (2) the structure of the agricultural biotechnology industry, which is dominated by agricultural chemical companies; and (3) patent law and industry policies that prevent farm households from saving transgenic seed and tailoring transgenic crops to their local environmental conditions.

## **Can Modern Biotechnology Be Used to Enhance Food Security?**

Use of modern biotechnology techniques in agriculture has been referred to by some scientists as the "doubly green" or "gene revolution," pointing to the possible benefits of using such technologies in meeting the world's future food needs. However, the majority of current acreage devoted to GE crops consist largely of export cash crops such as corn, soybeans, and cotton as opposed to more nutrient-dense crops found in the developing world, such as cassava, millet, pulses, bananas, beans, and squash. Because of the way in which GE crop technology has been deployed to date, some scientists have expressed concern that adoption of GE crops in the developing world could result in increased farmer dependence on chemically based pest control methods and could cause farmers to adopt a few modern crop varieties in place of their many locally indigenous crop varieties. Increasing the area sown to a

smaller number of modern crop varieties can increase economic risk to farmers because modern crop varieties may be more vulnerable to disease and pest attack compared with locally adapted indigenous crop varieties.

One area in which modern biotechnology techniques may increase food security is through enhancing genetic diversity in banana production. The Food and Agriculture Organization (FAO) has urged banana producers to promote greater genetic diversity in commercial banana production and has specifically called for (1) development of more diversity in bananas, (2) promoting awareness of the inevitable consequences of a narrow genetic base in crops and the need for a broader genetic base for commercial bananas, and (3) strengthening plant breeding programs in developing countries for banana and other basic staple crops. Such changes are possible because small-scale banana producers around the world have maintained a broad genetic pool, which can be used for future banana crop improvement. Furthermore, because more than 50% of the banana germplasm are sterile, biotechnology and mutation breeding are important tools that can improve banana varieties without the threat of genetic drift. A recent project that used modern biotechnology techniques as a way in which to benefit small-scale banana producers in Kenya resulted in an increased yield in banana production and projected additional income for farmers who participated in the project. However, according to the FAO, "genetically modified products are usually developed for large-scale commercial interests, and with a few exceptions, small-scale farmers have so far not benefited from the technology."

Advances being made in agriculture using modern biotechnology are also taking place using classical breeding and ecological approaches to disease control. For example, field research conducted in China has produced very encouraging results through an approach to disease management called intraspecific crop diversification. Rice fields in 5 townships were planted, a mixture of rice cultivars that were susceptible and resistant to rice blast disease, the region's major pathogen. Yields rose 89% and blast severity fell 94% in the fields that planted the seed mixtures compared with the monoculture controls. Because scientists' current understanding of polygenic (pertaining to or caused by several genes) traits is fairly rudimentary and their ability to identify the many genes involved is limited, most agronomically important traits--such as quality, adaptation to diverse environments, and tolerance to stresses--which are all polygenic traits, have yet to benefit from the use of genetic engineering. Therefore, classical plant breeding will be the primary means of improving these traits until more is learned about how a large number of genes act and interact to affect complex traits.

From a food systems perspective, it is important to acknowledge the broader social and economic contexts in which technologies are introduced. As noted by Babcock and Francis,

*Historically, the introduction of new technologies has disproportionately benefited men who grow commercial crops and have pre-existing resource advantages (e.g., land and cash for inputs) and greater attention from government extension workers. In contrast, women are more likely to produce food for the family. More total food produced may or may not translate into more food consumed by household members.*

Thus, to solve the problems of global malnutrition, hunger, and food insecurity, gender inequity must be acknowledged and addressed. Equity between men and women in the ability to access natural resources, such as land and water, is a critical component for improving the livelihoods of the poor and achieving global food security because women represent the largest group of the poor globally. An evaluation of whether GE crops will improve the nutritional value of foods and help eliminate malnutrition will depend on which particular food crops are targeted. According to Messer, "in the case of products targeted at needy consumer groups, such as golden rice for developing countries, GMOs are unlikely to contribute to their nutrition because their nutritional status is an artifact of overall conditions of poverty, and because the products are unlikely to be available in an affordable form any time soon."

Whether GE crops will improve access to food for those who otherwise lack land, wage, or social security entitlements will depend on the political-economic contexts in which GE technology is introduced. These include land reform, fair wage structure, labor's right to organize, and the technological and economic choices made by governments about the mix of farming and other livelihoods to promote. Other macrolevel economic and policy forces must also be assessed: unfair trade practices, unpayable debt burden (particularly in Africa), and macroeconomic policies that are imposed onto developing countries by donor agencies (eg, International Monetary Fund). These issues have been described in more detail elsewhere.

## **MOVING TOWARD A MORE INFORMED DIALOGUE**

In an attempt to move toward a more informed dialogue on GE foods and crops, policy makers and biotechnology advocates need to look beyond the public opinion polls for answers. Although information from these polls may be helpful in providing answers to "yes" and "no" questions and in gauging awareness, these polls cannot adequately articulate the values that underlie the public's perception of this technology. Communicating the achieved and potential benefits of agricultural biotechnology and GE foods must also be constrained by reality. It is imperative not to oversell the technology by focusing on benefits that are largely hypothetical, including consumer benefits, when the vast majority of benefits accrued have been to producers and multinational companies in industrialized countries. The United States also needs to move beyond science by having individuals in government and industry understand and respect the ethical, social, and cultural values of a diverse public. Relying only on scientific assessments of risks and benefits as tools to address public concerns about GE foods will not address the moral concerns that motivate the acceptance or rejection of GE foods, nor will it likely result in a successful resolution to the current WTO trade dispute on GE foods between the United States and Europe because differences in their regulatory policies reflect diverse cultural perceptions regarding food, nature, science, and government as opposed to ignorance or an irrational fear of the unknown.

In the future, both the private and the public sector must rethink their reasons for and methods of committing to public engagement. This is because the purpose of public engagement is not to facilitate acceptance of a product but rather to facilitate the appropriate development of technologies and products used by producers and consumed by the public. Entering a dialogue with people as citizens requires that the public be consulted before the research and development process is completed, which will necessitate a commitment of time, money, energy, and honesty. Rather than managing the social consequences of new applications of modern biotechnology in food and agriculture, both the government and industry must truly commit to informing, listening, and considering alternative views. This new approach will require a shift in public relations methodology used to engage in discussions with the public.

## **CONCLUSIONS AND RECOMMENDATIONS**

GE crops were introduced for commercial production in 1996. Since then, their use has increased rapidly. Thus far, GE crops and traits have primarily benefited farms and multinational companies in industrialized countries. In the future, increased public funding needs to be directed toward agricultural biotechnology research on nutrient-dense crops in the developing world. Increased public funding for other agricultural technologies, including agroecological farming techniques, is also needed. Improved gender equity (including improved access to resources) is needed to achieve global food security. Regulatory policy and market reforms are needed to ensure that modern biotechnology is used with consideration of the principles of social, economic, and ecological sustainability. Without such reforms, use of modern biotechnology and GE crops could exacerbate rather than reduce poverty and hunger in the developing world. Mandatory premarket approval and the provision of more complete testing

information should be required for GE foods that are currently being brought to market. When used with postmarket surveillance methods, labeling could be used to track any possible adverse effects of GE foods if they were to occur. Labeling and consumer right to know laws would provide consumers with a choice as to whether they wish to purchase GE foods.

Future GE crops that are developed and brought to market should be regulated by the precautionary principle. Because the precautionary principle is based on the need for transparent and inclusive decision making it allows for a broader set of determinants to be considered in the risk decision-making process. To better inform the public on developments related to modern agricultural biotechnology, nutrition educators need to become more familiar with the technical, social, economic, and cultural issues that are shaping the current debate on GE foods and crops. Despite cultural differences, Americans and Europeans share ethical values that could be used as a guide to engaging in a more informed dialogue on this issue. Such measures could increase the public's confidence in the government's ability to regulate GE foods, which would increase their acceptance of the technology.

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## **ENDNOTES**

Modern biotechnology refers to the application of (1) in vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (DNA) and direct injection of nucleic acid into cells or organelles, or (2) fusion of cells beyond the taxonomic family that overcome natural physiological, reproductive, or recombination barriers that are not techniques used in traditional breeding and selection.

Genetically engineered organisms are organisms in which material has been changed through modern biotechnology in a way that does not occur naturally by multiplication and/or natural recombination.

The World Trade Organization (WTO) was formed in 1995 at the Uruguay Round of the talks on the General Agreement on Tariffs and Trade (GATT). The WTO administers 29 different trade, investment, and trade-related agreements and is the only multilateral (supranational) organization with enforcement powers (either sanctions or fines). For more information on the WTO and international governance, see Labonte.

Living modified organisms (LMOs) are broadly defined as biological entities capable of transferring genetic material produced by modern biotechnological processes. LMOs is the official language used in the Convention on Biological Diversity to refer to genetically modified/genetically engineered organisms (GMOs/GEOs).

The International Union for the Protection of New Plant Varieties (UPOV) is an organization composed of 52 states whose primary purpose is to protect new varieties (the propagating material or seeds) through the granting of intellectual property rights or patents. The UPOV is based on the International Convention for the Protection of New Varieties of Plants, the UPOV Convention. Although originally meant to protect farmers' rights, the UPOV now only protects breeders' rights. Traditional indigenous knowledge is not protected by the UPOV.

More information on food sovereignty and Vía Campesina is available at

## FOOTNOTES

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