Food Systems and Dietary Perspectives: Are Genetically Modified Organisms the Best Way to Ensure Nutritionally Adequate Food?

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Food Systems and Dietary Perspective: Are Genetically Modified Organisms the Best Way to Ensure Nutritionally Adequate Food?

ELLEN MESSER*

INTRODUCTION

Close to twenty years ago, molecular biologists performed the first plant genetic transformation, heralding a new era in plant breeding, agricultural production, food processing, and nutrition. The new molecular and cellular biological techniques did not serve as a panacea or silver bullet to overcome world hunger, or as an easy remedy for the most significant problems of malnutrition. They instead offered promising but controversial new tools with which plant scientists might tailor materials to meet specific challenges or conditions of agricultural production systems, processor requirements, or consumer demand. From the outset, it was clear that the impacts of these genetically modified (GM) plant types and associated cropping systems on sustainable food systems would depend on the inventors' choices of which crop species and plant characteristics were modified. Potential benefits would also be shaped by the institutional contexts through which new seeding materials were produced and disseminated,¹ including organized promoters and detractors, government regulatory safety apparatus, trade rules, business interests, and consumer attitudes.²

By early 2001, a dozen genetically modified food-plant types with value-added characteristics of herbicide tolerance, insect resistance, disease resistance, and improved product quality were in the U.S. marketplace, with more in the pipeline and close to commercial release, according to the Biotechnology Industry Organization and its members.³ Almost all have been developed by a few large life-science firms, which have been buying up seed companies and start-up

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biotechnology firms to consolidate and concentrate seed and chemical agro-industries. A handful of developing countries, such as China, Thailand, Brazil, Mexico, South Africa, and Kenya, working with public-sector institutions, or through public-private partnerships, also have GM products close to commercialization.4 These private and public interests hail genetically modified organisms (GMOs) as an important solution for world hunger,5 and promise that GMOs will reduce malnutrition by (1) increasing food production, (2) lowering food production and consumption costs, (3) developing products to meet the special needs of nutritionally deprived groups, and (4) creating new livelihood possibilities through industrial employment and trade.

These proponents dismiss the criticism of GMO opponents, who argue that agricultural biotechnology, like other advances, will further compromise the competitive positions of poorer farmers and nations and increase the marginality of the rural poor. Other papers in this issue consider the principal biological, environmental, and health risks that suggest agricultural biotechnology might introduce more harm than good6 as well as some of the additional philosophical and ethical questions that GMOs raise.7 Detractors also worry that GMOs will marginalize other types of agro-ecological research and action that would help farmers become less dependent on external commercial factor supplies. They fear that penetration of GMOs into new environments that enjoy little regulatory oversight will impose additional hazards because they threaten to reduce biodiversity or introduce destructive new plant or insect pests. In these negative scenarios, hasty, under-regulated adoption of GMOs could damage crop production for everyone over the short, medium, or longer term.8 In part as a response to these criticisms, policymakers in Europe and elsewhere have been

embracing a precautionary—and slower—regulatory approach. Some proponents argue that exacting environmental-impact analyses, and other time-consuming risk evaluations, of GMOs will slow developments and prevent benefits from reaching disadvantaged farmers and countries any time soon. As it is, the commercial sector that dominates product development has very limited business incentive to create new products for poorer farmers who cultivate areas of lower agricultural potential. These farmers, who need new pest-reduction strategies, are often too poor to buy new seeds or chemicals. Similarly, agribusiness ordinarily envisions too little financial return to develop products targeted toward poor, malnourished consumers, who might benefit most from vitamin- or mineral-rich grains. Yet this private agribusiness sector controls the property rights to the most promising technologies, techniques, genes, and genotypes.

In the case of “golden rice,” agricultural biotechnology’s self-proclaimed humanitarians (energized by Ingo Potrykus, one of its inventors) have negotiated licenses with multiple institutions, so that the property-protected materials that go into vitamin A (carotene)-rich golden rice can be made available free or at cost to subsistence farmers in developing countries who would otherwise be unable to grow it to feed poor, vitamin A-deficient consumers of rice diets. So far, golden rice is exceptional because it is a product developed specifically to meet the nutritional needs of poor consumers and not for profit (although Syngenta, formerly Astra Zeneca, which holds a license does not rule out applications for profitable markets). Even so, anti-GMO “food first” activists are quick to cite its insufficiencies as a remedy for vitamin A deficiency or poverty, which is the underlying problem. Simply stated, GMOs are an attempt to impose a technological solution to a social problem, and are therefore not the best way to achieve a food-secure and well-nourished global population. Accepting this last proposition, it is nevertheless instructive to consider where GMOs fit into human food systems and diets, and how they might contribute to production of affordable, nutritionally adequate food.

10. McCouch, supra note 5, at 32-33.
I. GMOs, WORLD FOOD SUPPLIES, AND FOOD SECURITY

Since the 1970s, the world annually has produced more than enough food to supply every human being with a nutritionally adequate diet, but this food is not equitably distributed. Although World Watch Institute and other think tanks concerned about sustainable agriculture regularly or intermittently report a food and environmental crisis, more food could be produced if there were additional effective demand to pay for it. From the farmer’s perspective—at least in the industrialized world—the food crisis is the result not of insufficient production, but of insufficient markets for their products. Farmers find themselves squeezed between the technological possibilities of producing more food more efficiently and their ability to make a living from the sale of agricultural products. For example, in the case of potatoes in the year 2000, there was such a glut on the market that U.S. farmers chose to plow tubers into the ground as fertilizers rather than sell them at greatly reduced prices that would not have covered production costs. In theory, GMO virus- and beetle-resistant potatoes should help potato farmers reduce losses and so increase yields and income, and these producers should be able to pass on lower-per-unit costs to consumers. In reality, more potatoes at this point in time does not mean that there are more and cheaper potatoes in the marketplace for low-income consumers, although food banks salvage some of the excess. As another example, U.S. farmers who expand their soybean acreage, in part as a response to the availability of herbicide-tolerant GMOs that offer a new approach to elimination of weed damage, may find themselves dependent on U.S. support-price purchases when unable to sell their beans on the open market because the world price has slipped below what, given their input costs, are profitable levels.

Such surpluses among industrialized farmers notwithstanding, food shortages persist in many developing countries that confront the combined challenges of equitable food production and distribution. Some 791 million people in the developing world, two-thirds of them living in rural areas, are food-insecure, which means they lack access to adequate food (at least 2,250 kcal/day) to meet their nutritional needs for an active and healthy life. Nutritional public health


surveys indicate there are also large numbers suffering from specific forms of malnutrition. Some 160 million children under five in the developing world are malnourished as a result of inadequate food, health, and care.\textsuperscript{14} More than 100 million young children and many of their mothers, predominantly in South and Southeast Asia, are at risk of vitamin A deficiency, which in its severe form can cause blindness and death. Roughly half of females of reproductive age suffer some degree of iron-deficiency anemia.\textsuperscript{15}

Projecting food insecurity into the future, economists foresee continued high numbers, as human population and demand for adequate nourishment continue to grow. The International Food Policy Research Institute estimates that between 1995 and 2020 global demand for cereals will increase by thirty-nine percent, for meat by fifty-eight percent, and for roots and tubers by thirty-seven percent.\textsuperscript{16} Eighty-five percent of the demand for cereal and meat will occur in developing countries as a result of growing populations, modest income growth, and urbanization, which change food habits toward a richer diet with less bulk.\textsuperscript{17} China alone may account for twenty-five percent of the increase in demand for cereals and forty percent of the increased demand for meat.\textsuperscript{18}

Agricultural researchers and economists insist that biotechnology must play an important role in meeting this challenge. Panels of experts, while acknowledging that most hunger today is due to lack of economic access rather than availability of food in the market, caution: [T]here is no room for complacency in relation to the adequacy of the food supply . . . a solution to securing world food supplies while preserving the environment is virtually inconceivable without recombinant genetics and biotechnology.\textsuperscript{19} Gordon Conway, the president of the Rockefeller Foundation, adds:

\begin{itemize}
  \item \textsuperscript{16} Pinstrup-Andersen & Pandya-Lorch, supra note 14 at 6.
  \item \textsuperscript{17} Id.
  \item \textsuperscript{18} Id.
\end{itemize}
Genetic engineering has a special value for agricultural production in developing countries . . . creating new plant varieties that not only deliver higher yields but contain the internal solutions to biotic and abiotic challenges, reducing the need for chemical inputs such as fungicides and pesticides, and increasing tolerance to drought, salinity, chemical toxicity and other adverse circumstances.²⁰

But informed responses to the question of the role of GMOs in solving problems of food production and consumption require answers to four separate queries: First, will GMOs ensure production of adequate food to feed everyone an adequate diet? Second, will GMOs help everyone to enjoy sufficient entitlements (access to land, income, and social security resources) to establish effective demand for adequate nutrients? Third, will GMOs provide affordable ways to meet the special needs of nutritionally vulnerable groups, such as children, reproductive-aged women, and the elderly, especially those who suffer economic disadvantages out of the mainstream of the formal economy? Finally, are GMO production and processing methods sustainable?

A. Will GMOs Ensure Production of Adequate Food for All?

The brief answer to this question is that adequate food for all depends on what people are eating. Diets that are basic, composed entirely of plant foods, or only slightly enriched with a small proportion of animal products, stretch food supplies to feed more people than diets that are rich in products from animals. In addition, it is important how the complementary livestock-based portion of the diet is produced—whether the livestock are range-fed, fed by crop residues, or fed grains, which might otherwise be used to feed human beings directly.

1. Plant Selection, Agricultural Technology, and Human Nutrition

Human beings acquire nearly all their carbohydrates and more than half of their protein from plant sources, and nearly all animal products in modern industrialized societies are the end products of cultivated-plant feeds. Most of this food intake is derived from a very narrow range of plant species. When

human beings began to produce food some 10,000 years ago, humankind went from what had been procurement of a broad spectrum of plant and animal foods to a much narrower range of cultivated plants. Most were angiosperms (flowering plants), and most were propagated by seed, with a smaller number multiplied from cuttings of stems, roots, and tubers.\(^{21}\)

Over the millennia, farmers achieved large increases in food production by carefully selecting plant types that yielded more per unit area, water, or per individual plant, and also by modifying the environments into which groups of species (multi-cropping) or single species (monocrops) were introduced. As understandings of the physical, chemical, and biological parameters of plant production increased, the nineteenth century and twentieth centuries witnessed chemical (fertilizer) and mechanical revolutions in agriculture. Their impacts were magnified by several major steps of bio-revolution in the twentieth century: the development of hybrids (especially in corn from controlled crosses of inbred varieties since the 1930s); large productivity increases in soybean production after the 1940s and 1950s based on new processing methods and improved understandings of the relationships between vegetative growth, flowering, and day length; and improvements in the food qualities of the oilseed crops, cotton and canola, through elimination of toxins in the 1970s.\(^{22}\)

Applying elements of modern plant breeding and chemical agronomy, beginning in the 1940s the international agricultural research community invested in a green revolution for the developing world. This seed/water/chemical research made available to third world nations modern varieties of rice, wheat, potatoes, and to a lesser extent coarse grains, which produce more under advantaged growing conditions because they are more highly responsive to inputs of moisture, fertilizers, and protective chemicals. In the present and future, availability of good quality water and soils for agriculture may prove as important as improved seeding materials, so plant, water, and soil scientists increasingly work together to develop new, more highly productive field systems that take advantage of improved seed, soils, chemicals, and pest- and water-management technologies.


\(^{22}\) See id.; see also Ellen Messer, Maize, in The Cambridge World History of Food 97 (Kenneth F. Kiple & Kriemhild Coneé Omelas eds., 2000).
2. Genetic Modification

Agricultural biotechnology involves the in vitro manipulation of whole plant, cellular, or molecular materials for the purpose of improving agricultural plants or processes and next steps in plant design. In contrast to conventional plant breeding, which transfers pollen between selected individuals in closely related varieties, genetic engineering utilizes recombinant DNA techniques to transfer genes between species and cellular and tissue-culture techniques to regenerate new varieties of whole plants. Through selected gene transfers between species, GMOs are able to draw on a wider range of genes and offer useful phenotypes unachievable by conventional breeding or alternative biotechnologies, such as mutation selection breeding or somaclonal variation. The production of GMOs incorporates cell- and tissue-culture techniques that have been available since the 1950s, gene cloning techniques that have been used since the 1970s, and plant genetic transformation systems developed since the 1980s. In the 1990s, scientists significantly made the steps of plant transformation from gene transfer through whole plant regeneration routine, and scientists declared that no species remained recalcitrant to transformation. But many unknowns persist in each step, as does the fundamental challenge of transferring and controlling the expression of more genes that control useful phenotypes.

Like commercial hybrids, but in contrast to the Green Revolution in agriculture across the developing world, GMOs are being developed almost entirely in the private sector, where private firms attempt to patent and control the licensing of methods, processes, and products. This means that in addition to scientific and technical challenges, developers also face proprietary hurdles, as private interests surround and limit access to almost all steps in the process from gene transfer to plant multiplication. As knowledge of biological processes and products expands, GMOs therefore offer great promise for improving the nutritional qualities of different foods. “The application of biotechnology, in terms of using the full range of scientific biological information available, is in its infancy . . . the pipeline is full of new products . . . Understanding the structure and function of every gene in a plant will lead to many innovative applications.”

23. See Messer & Heywood, supra note 1, at 344-45.
But beyond biological potential, institutional and economic contexts must also be favorable. Developers, producers, and consumers must accept GMOs, so that the genetic modification contributes to superior nutritional qualities in the plant foods and diets that people, especially poor people, eat. Additionally, economists must demonstrate first, that plant-breeding approaches are more cost-effective than alternatives, such as water or chemical management of the environment; second, that biotechnological techniques are superior to conventional techniques; and third, even if the first two conditions are satisfied, that GMOs create no negative agronomic consequences, that consumers will accept the new products, and that the new products will result in significant improvement in the nutritional status of malnourished populations.

3. Plant Families and Dietary Categories

Of the more than 200,000 species of flowering plants, only about 2,000 have ever been domesticated; of these, only a few dozen are significant sources of food. Of these, the most important are the cereal grasses (Graminae), often glossed “the staff of life,” which include wheat, corn, and rice. These three grains comprise three of the top four food crops by weight (potato, a tuber, ranks third in this group). Less common cereals, lumped into the category of “coarse grains,” are barley, sorghum, oat, and rye. Cereals, which contain mostly carbohydrates (four calories per gram), contribute between ten and fourteen percent protein calories (also four calories per gram), and corn is also high in oil (nine calories per gram). High-fructose corn syrup, which increasingly replaces cane and beet sugar as a sweetener, provides a good example of the ways in which enzyme technology, another class of “biotechnology,” has transformed human food systems, the value of a principal crop, and world grain and food trade.

A second category of food plants are the legumes (Leguminaceae), often glossed the “meat of the poor” because they are high in protein and usually inexpensive relative to meat. Agriculturally and economically, the soybean is the most important legume; it is thirty-eight percent protein and eighteen percent fat. Although it is used predominantly as animal feed, it also serves as a meat substitute or extender and accounts for seventy percent of the edible oil that fattens human beings across the globe. Dry beans (Phaseolus vulgaris) come in hundreds of varieties and there are also grown many types of peas (Vigna or Pisum), lentils (Lens), and minor species with multiple varieties. The peanut,
which is twenty-six percent protein, but an important source of oil, is also a legume.27

A third plant category, not restricted to a single plant family, are the oilseeds, which offer concentrated sources of calories—essential fatty acids—and raw materials for industrial products such as lubricants. In addition to soy, important sources of oil include coconut and other tropical palms, sunflower (a member of the Compositae family) and mustard (Brassicaceae). The last, oilseed rape—which has undergone a name change to canola to accommodate English-speaking sensibilities—has enlarged in importance as a result of improved breeding and processing (since around 1975) which lower erucic acid and so improve the oilseed’s palatability and healthfulness. Cottonseed, which has been pressed for oil for about one hundred years, has also become more valuable after a revolution in processing separated the seeds, which could be processed into oilseed cake (for animal feed) and oil. Plant breeders also reduced gossopol, a toxic substance, but reduction of gossopol, the plant’s natural protection, also renders cotton more vulnerable to insect damage, and raises requirements for chemical or other sources of protection.28

Starchy staples comprise the fourth major category of plant foods, which are mainly carbohydrates. These are primarily roots and tubers, the most important of which is potato (Solanum tuberosum), which comes in hundreds of varieties. It is followed by sugar beet, in the Chenopodiaceae family, manioc (Manihot esculenta), an important subsistence crop and starvation food in Africa and Asia, and also an important source of edible or industrial starch; sweet potato (Ipomoea), which is also a poor person’s subsistence crop in Africa and Asia, yams, bananas and plantains, taro, and breadfruit.29

All of the above fall into the category of primary and secondary staple food crops, which form the basis for cooked meals in most societies. They are functionally diverse because they serve as human food, animal feed, and also non-food products, with uses continually expanding or changing depending on the economics of crop production, processing, and rules of trade. These economic forces largely shape farmers’ choices of which varieties to grow in what types of field systems, and plant breeders’ choices of which characteristics to target for improvement.

27. See HEISER, supra note 21.
28. Id.
29. Id.
FOOD SYSTEMS AND DIETARY PERSPECTIVE

Additional plant categories, which serve as accompaniments to the main courses composed of the complementary proteins of cereals and legumes, are vegetables, fruits, nuts, and beverages. With the exception of nuts, these are low in calories, but contain diverse micronutrients, the vitamins and minerals that are necessary to sustain human metabolic processes, growth, and maintenance. Economically, the most important vegetable is cabbage (Brassica oleracea), which comes in many varieties. Other important vegetable and condiment crops are onions and garlic, which comprise components of nutrient-dense sauces that complement and garnish main staple food dishes. Additional foods enter the diet mainly as "snacks" rather than in meals. Of the fruits, grape is the most important; others are tomato, orange, apple, watermelon, mango, pineapple, in that order. Spices and condiment crops include flavorings, such as vanilla, confectionary crops such as chocolate, and spices such as capsicum (chili). Important beverage crops, besides the grape, include coffee, tea, chocolate, and cola.  

4. Which Crops Have Been Subject to Genetic Modification

Worldwide, more than 120 plant species in thirty-five families can be transformed, and no species is classified as recalcitrant to gene transfer and regeneration (from cell culture into a whole plant). Some, such as cassava, which is a principal food crop of the poor in Africa and Southeast Asia, took longer than anticipated to achieve successful transformation systems. As recently as 1992, major grasses such as rice, maize, and wheat could not be reliably transformed, but such barriers have now been overcome. 

Although the private sector has been faulted for focusing on major commercial crops and bypassing crops that feed the poor, research in major crops such as maize and rice is accelerating the pace of biotechnology achievements across species. Scientists working on particular points of transformation systems and particular genetic loci coding for specific desirable characteristics often work on multiple genera and species within plant families. The range of crop characteristics that molecular biologists can manipulate is also expanding. Genetic engineers control increasing numbers of genes coding

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30. Id.
for particular herbicide tolerances, insect and disease resistance, and altered nutrient composition, including the relative quantity and quality of carbohydrates, proteins, and fats, usually in seeds. In the United States, maize, soybean, cotton, canola, potato, tomato, and squash varieties have been commercialized. In the U.S. pipeline are maize and soybean varieties boasting higher energy (more fat), healthier fat composition, more balanced protein, designer starches, and enhanced digestibility. Each variety is tailored to particular nutritional conditions, industrial processes, or other end uses. Scientists can also manipulate genes that control the timing of fertility (significant in drought-tolerant maize), sterility (significant for seed developers' protection), and ripening (which allows a host of fruit, vegetable, and snack crops extended shelf life and superior flavor and texture). Additional crop characteristics in the pipeline allow plants to express valuable flavor, pharmaceutical, or plastics components.

Choices of which crops and characteristics to develop are influenced by "what farmers want" (to overcome yield-limiting factors and to make money), what is commercially desirable (based on market assessment of what consumers, including processors, want and are willing to pay for), and what is technologically feasible. Most transformations to date have focused on agronomic characteristics that enhance yields by preventing losses to pests. Theoretically any food plant

32. Since 1983, private commercial firms have been trying to hurry GMOs to market, while the USDA, Federal Drug Agency (FDA), and Environmental Protection Agency (EPA) provide a set of regulatory screenings that are meant to protect consumer safety, the U.S. food supply, and the environment. USDA Animal and Plant Health Inspection Service (APHIS) sets the experimental protocol for field release (field testing) by which GMOs are judged to pose no environmental hazard and posts data regarding what crop trials have been filed. Over its first 10 years, APHIS approved field releases in 44 different plant species. Maize was the most frequent, with 1,420 field releases between 1987 and November 1997, followed by tomato, potato, and soybean, each with more than 300 releases and cotton with 237. Twenty-six species each had fewer than five releases. Messer & Dudnik, supra note 2, at 31.

Over this same period, APHIS reported issuing almost 3,700 permits and acknowledged notifications for 9 different phenotypes (modified characteristics). The largest number (29%) was for herbicide tolerance, followed by insect resistance (24%) and product quality (21%). Viral resistance was close to 10%, fungal resistance just over 4%. Together, marker genes, bacterial resistance, and nematodes accounted for 7%. Agronomic properties, such as environmental stress tolerance accounted for only 4%. Id.

Of the initial 34 varieties approved by the USDA and FDA, 8 were maize, followed by 6 tomato, 5 soybean, 5 cotton, 4 canola, 3 potato, 2 squash, and 1 chicory. APHIS data also indicated that most of the GMOS are being developed in the private sector by a few large firms. In maize, as a case in point, the vast majority of petitions came from only 5 companies: DeKalb Genetics (a subsidiary of Monsanto), DuPont, Pioneer Hi-Bred (now a subsidiary of DuPont), and Northrup-King (Novartis). Id.

Since 1994, the year Calgene's Flav'r Sav'r (MacGregor) tomato was commercialized as the first approved GMO, the prevalence of GMOs in U.S. agriculture has soared. In 1997, GMOs accounted for 20% of maize, 40% of soybeans, and 50% of cotton. Id. By 1999, these numbers were 37% of maize, 47% of soybeans, and 48% of cotton. Biotech. Indus. Org., 1999 Acreage Data on Biotechnology Crops, http://www.bio.org/food&ag/1999Acreage.html (last visited Dec. 19, 2001).
species is amenable to transformation, but scientists have focused on the major field crops, such as cereals, soybean, canola, and cotton, plus a few specialty crops, such as salad crops, fruits, and vegetables. Many more crops could be transformed into commercial GMOs, however, if the economics were right. Producers and consumers have also learned that GMOs can very quickly penetrate food systems, intentionally or unintentionally. Private developers have intentionally saturated the seed market for insect-protected and herbicide-tolerant field crops. These commercial successes with farmers have unintentionally demonstrated to consumers that GMO maize, soybean, and oilseed components now enter most processed food in the United States, a finding that consumers do not necessarily welcome. The Starlink Corn public-relations debacle of 2000 and 2001 raised an outcry over the issues of consumer choice, the need for product oversight, segregation, and labeling, and crop contamination. In some instances, GMOs were apparently harvested where they were not sown. These issues, which have not yet been resolved, are likely to influence sustainability of GMOs in that they influence public opinion, and the public is beginning to influence government oversight and to penetrate company development and promotional strategies.

GMOs so far are restricted mainly to single-gene or stacked single-gene traits, such as selected herbicide tolerance and insect resistance, but golden rice suggests a technological advance, in that it introduces four genes, indicating that more complex and ambitious multi-gene transfers are possible. What is commercially desirable, however, depends not only on available techniques but on ecological constraints, the availability and costs of alternative remediation strategies, and the profits private developers can expect from a GMO advance. Private firms also base decisions on the expense or difficulty of securing patents and licensing agreements to produce products, on the regulatory environment, which may delay or prevent release of a product, and on prevailing international trade agreements, which may restrict markets, and ultimately on public acceptance and effective demand. These commercial aspects raise additional ethical concerns, even among those who view GMOs as a desirable tool against hunger. They ask pressing questions, such as whether biotechnology tools will be available to improve crop varieties for disadvantaged peoples and countries, especially in the developing world. Legal property rights over genes, plant parts, and whole plant organisms also raise profound ethical issues about human relationships with nature: whether nature should be commercialized, and whether
any part of the earth's genetic heritage can be privatized for profit by private interests.\footnote{See Messer & Dudnik, supra note 2, at 33-34.}

**B. Will GMOs Help Everyone Enjoy Sufficient Entitlements, to Establish Effective Demand for Adequate Nutrients?**

The simple answer to this question is it depends on what crops are developed, who grows them, and at what price they are made available to consumers. GMOs carry the potential for production of more and cheaper food. But in order for that food effectively to reach those who are food insecure, developers must target products that can improve the productivity and incomes of smaller farmers, particularly those in developing countries. For sustainable production, public and private sector actors also must ensure that reliable markets exist, and that additional responsible institutions are in place to minimize and address risks as they arise.\footnote{See generally NAT'L AGRIC. BIOTECH. COUNCIL, REPORT 11: WORLD FOOD SECURITY AND SUSTAINABILITY: THE IMPACTS OF BIOTECHNOLOGY AND INDUSTRIAL CONSOLIDATION (Donald P. Wekes \textit{et al.} eds., 1999).} Most developments to date have focused on the first stage of production, but commercial commentators caution that institutional constraints, including consumer and/or farmer backlash over large commercial firm control of biotechnologies, could stall or reverse developments.\footnote{See e.g., Paul Raeburn, Where Do We Go From Here? The View from Times Square, in WORLD FOOD SECURITY AND SUSTAINABILITY: THE IMPACTS OF BIOTECHNOLOGY AND INDUSTRIAL CONSOLIDATION, supra note 34, at 149.}

Agricultural planners argue that the only way to meet food, fiber, and feed challenges of the coming years is by agricultural intensification via biotechnology. Moreover, given patterns of production and trade, these technologies must be applied in developing countries. That is, much of this additional food production must take place in the countries of consumption, where it can improve rural incomes, increase accessibility to low-cost food by the poor, and also be implemented in sustainable “doubly green”\footnote{CONWAY, supra note 20, at 41.} or “evergreen”\footnote{M.S. Swaminathan, Genetic Engineering and Food Security: Ecological and Livelihood Issues, in AGRICULTURAL BIOTECHNOLOGY AND THE POOR 37, 37 (G.J. Persley & M.M. Lantin eds., 2000), available at http://www.cgiar.org/biotech/rep0100/swaminat.pdf.} ways that refer to both environmental and social institutional continuity. But early developments leave the outlook unclear as to who will fund the adaptive research necessary to apply the findings that already exist to the problems of developing countries.
Developing-country researchers already find themselves restricted in the use of property-protected constructs and processes if they wish to develop products to trade in international markets. The usual suggested solution to overcome both impasses of financing and intellectual property protection is for developing country institutes and scientists to form public-private partnerships, which can advance the research and development agendas of third world institutes, and sometimes train developing country scientists who advance understandings and applications of technologies that have already been commercialized. A leading “honest brokerage” institution is the International Service for the Acquisition of Agro-biotech Applications (ISAAA), with its mission to facilitate the “acquisition and transfer of agricultural biotechnology applications from the industrial countries, particularly proprietary technology from the private sector, to developing countries for their benefit to ensure that agricultural biotechnology can “contribute to poverty alleviation, by increasing crop productivity and income generation, particularly for resource-poor farmers, and to bring about a safer environment and more sustainable agricultural development.”

ISAAA regularly reports on the status of GMO crops sown worldwide, as well as its own successes in matching developing country institutions with private firms or farmers. Some early examples of their deals include the development of virus-resistant potato cultivars in Mexico; development of transgenic papaya cultivars resistant to ring-spot disease, for possible cultivation in Brazil, Thailand, and Venezuela; and the development of insect-resistant cotton, which brokered Monsanto technology to Zimbabwe, Brazil, and Argentina. But most of their programs rely on grants from international or bilateral donors, such as the United States Agency for International Development (USAID), whose funds have proved unsustainable.

Alongside such efforts, developing countries have launched their own plant biotechnology, targeting crops that are especially important to them in subsistence and trade, for which biotechnology-assisted breeding offers advantages in overcoming production constraints or enhancing product qualities. China may be the most advanced, and anticipates major increases in product quality and quantity

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38. See e.g., Luis Herrerra-Estrella, Transgenic Plants for Tropical Regions: Some Considerations About Their Development and Their Transfer to the Small Farmer, 96 PROC. NAT'L ACADEMY SCI. U.S. AM. 5980 (1999).
in its staple (rice), secondary staple (maize), and other crops. Chinese scientists and developers may be able to get around many intellectual property rights (IPR) constraints by using marker-assisted breeding rather than GMOs, which involve additional layers of negotiation over processes and constructs.\textsuperscript{42} Scientists from Thailand report genetic manipulation in a number of target species, including major export crops such as cassava, which has been bred for higher starch content, a principal industrial component.\textsuperscript{43} Mexican scientists anticipate national and global returns to GMOs designed to tolerate acidic soils, but also worry about gene transfer to native cultivars and wild relatives of maize.\textsuperscript{44} Scientists in Brazil, where the population consumes large quantities of beans, have achieved a virus-resistant cultivar. Thus, biotechnologies are entering plant breeding programs in developing countries where they are being adapted to locally important plant species and problems.

Internationally, scientists from Latin America to Asia and Africa also anticipate huge returns on the transfer of genes from teosinte and Tripsacum, wild predecessors to maize, which offer new approaches to \textit{Striga} (weed) resistance, and also the possibility of asexual production of seeds, including high yielding hybrids, through apomyxis, which is under genetic control.\textsuperscript{45}

Such preliminary laboratory advances notwithstanding, most countries still try to maintain strict control over field testing of new transgenic cultivars, because they fear damaging escapes. Moreover, the next steps from field to marketplace remain underexplored. Once genetically improved crops are deemed advantageous and safe, will there be adequate public or private mechanisms by which seeds will get into the hands of small farmers who might benefit from growing them? Also, will there be follow-up monitoring and replacement breeding to keep up with plant pests? These are some of the institutional, or political-economic constraints, that may keep GMOs from contributing to the livelihoods and food supplies of the food insecure. Additional institutional constraints at scientific and business levels include the paucity of opportunities that exist for the training and employment of developing-country scientists in their

\begin{itemize}
\item[42.] Qifa Zhang, \textit{China: Agricultural Biotechnology Opportunities to Meet the Challenges of Food Production}, in \textit{AGRICULTURAL BIOTECHNOLOGY AND THE POOR}, supra note 37, at 45, 49.
\item[43.] Morakot Tanticharoen, \textit{Thailand: Biotechnology for Farm Products and Agro-Industries}, in \textit{AGRICULTURAL BIOTECHNOLOGY AND THE POOR}, supra note 37, at 64, 67-68.
\item[44.] See Henera-Estrella, \textit{supra} note 38, 5979-80.
\end{itemize}
countries of origin, and of institutional mechanisms that enable the distribution of IPR-protected materials to those working on developing-country problems.\textsuperscript{46}

Overviews of the “social risks” of the new technologies emphasize that even where GMOs reach developing countries, without additional institutional mechanisms to ensure that the seeding materials reach poorer farmers, their proposed benefits are likely to be captured by already wealthy farmers, who can afford the new inputs, which often include chemicals as well as seeds.\textsuperscript{47} Although proponents look forward to eventual benefits for all and sustainability in an era of computer-assisted precision agriculture, which will spare inputs and optimally manage germplasm,\textsuperscript{48} these sustainable future scenarios are still far off, and, if resistance holds, might not involve GMOs at all.

C. Will GMOs Provide Affordable Ways to Meet the Special Needs of Nutritionally Vulnerable Groups?

GMOs carry a large potential nutritional impact to increase the amount of calories, quality protein, healthful fat and starch, and micronutrients per crop and unit area or inputs.\textsuperscript{49} As suggested above, early developments have produced GMOs with benefits mainly scheduled to accrue to animal nutrition and those in wealthier countries. But oilseeds with healthier composition, and grains and legumes with better tasting and more digestible protein, are in the pipeline. In addition, proponents argue that the GMO crops that will make the biggest difference to the largest numbers of people are those that carry more of the essential nutrients otherwise lacking in poor people’s diets, such as iron and vitamin A.

So far, there is no indication that GMOs are replacing traditional crops or cropping patterns. But crop developers should pay more attention to diets that people traditionally eat or choose, and to what impact GMO crop choices might have on availabilities of these traditional foods. In the early 1970s, in two very distant parts of the world, introductions of improved crops resulted in a sharp decline in legume production, where legumes were truly “the meat of the poor.” In India, monocropped green revolution rice and wheat reduced areas sown to

\textsuperscript{46} See Herrerra-Estrella, supra note 38, at 5980-81.
\textsuperscript{47} See, e.g., Per Pinstrup-Andersen & Marc J. Cohen, Modern Biotechnology for Food and Agriculture: Risks and Opportunities for the Poor, in AGRICULTURAL BIOTECHNOLOGY AND THE POOR, supra note 37, at 159, 167.
\textsuperscript{48} See, e.g., Swaminathan, supra note 37.
mixed cereal-legume crops, and in Brazil, a surge in soybean production at the expense of areas sown in common beans produced a short-term crisis in bean supply. Apart from soybeans, which supply seventy percent of the world's processed edible oils, many food additives, some alternative protein, but mostly animal feed, legumes have not received great attention from plant molecular biologists or companies, which focus instead on how to enhance the protein component or oil content of single crops, usually cereals. In retrospect; attempts to introduce high-protein grains in the 1960s through the 1990s stumbled on the technical difficulties of producing high-yield nutrient-rich grains that had all of the other desirable agronomic and culinary characteristics that growers and consumers desired. This history is mostly sidelined in the current excitement over golden rice, a prototype variety that contains three genes that allow it to synthesize beta-carotene in quantities sufficient to meet vitamin A deficits of low-income consumers.

Carefully framing their arguments, proponents of golden rice note that much of the world’s vitamin A deficient population eats rice daily and depends on it as their chief source of calories, macro nutrients, and micronutrients. They also cite UNICEF’s epidemiological projections that predict improved vitamin A nutrition could prevent one to two million deaths each year for children under five. In addition, it has been argued that beta-carotene provides additional health benefits, such as reduction of risk of certain types of cancers, cardiovascular disease, and age-related macular degeneration. They assert there are no known harmful effects of high beta-carotene intake levels. Therefore, any variety of rice which can provide beta-carotene (or other carotenoids) in sufficient quantities to meet the vitamin A deficits has obvious benefits.50

Moreover, the GMO engineered in this case appears to allay some of the specific fears about foreign genes presented by other GMOs. The golden gene is expressed only in the endosperm, which eliminates the possibility of accidental introduction of a foreign gene into the growing environment during the plant’s life cycle. The cotransformation strategy employed for the genetic modification should enable the scientists to segregate the selectable marker gene (for antibiotic resistance) away from the genes of interest. This means that consumers will not ingest this additional foreign DNA, another source of concern that has been voiced by critics. In addition, scientists emphasize that rice plants have a natural

pathway for carotenoid synthesis, so golden rice is a natural food, not some monstrous "Frankenfood" hybrid.\textsuperscript{51}

Happily, it should be easy to recognize GMO golden rice because of its color, so once the rice gets out of the lab, it will be obvious which varieties contain the golden gene, and so eliminate the need for a marker gene. Ironically, yellow color may constitute a major source of resistance by potential consumer populations because most prefer white, not yellow, rice. This feature is underemphasized by promoters, but nutritionists remember that in a past attempt to enrich rice with thiamine, yellow thiamine pellets that had been mixed into ordinary rice were painstakingly removed by Thai consumers, whose thiamine-deficiency was the target of this unsuccessful nutritional intervention. Although populations which value rice colored with golden turmeric may readily accept the new variety, it may be a hard sell to others.\textsuperscript{52}

There are also many steps involved before any agricultural or consumer product is available. Field tests must demonstrate whether there are any metabolic tradeoffs, which produce unanticipated changes in the size, shape, fertility, seed-set, or resistances and tolerances of the plant. Additional nutritional and biochemical testing must show whether there are additional tradeoffs in consumer safety, health, or desirability characteristics.

High-lysine maize, as a case in point, proved to have textural characteristics making it impossible to process good tortillas. Its yields were lower and post-harvest losses higher. These findings sent it back to the lab, where it took another decade of biochemical and breeding research to overcome these complicated design flaws. In the interim, the nutrition community lost interest in quality-protein maize (QPM) as a priority problem, and in grain-based rather than dietary-diversity based nutritional strategies. It is only very recently that new breeding stocks of QPM have been released, and taken up by national breeding programs, with the best outlook in China.\textsuperscript{53}

In the case of vitamin A deficiencies, supplements currently are distributed to children at risk in what constitutes an alternative strategy, which proves largely effective where health posts are fully operative and people use them. Proponents of golden rice argue that the alternative grain-based strategy puts control of vitamin-A deficiency in the hands of the farmer-consumers, who will benefit in

\textsuperscript{51} Id.
\textsuperscript{52} See Messer & Heywood, supra note 1, at 341-42.
cases where health programs are disrupted or unsustainable. They suggest that
the use of biotechnology is justified where it can be established that (1) plant
breeding is more cost-effective than alternative interventions, (2) biotechnology is
superior to conventional techniques, and (3) there are no serious negative
agronomic consequences, or objectionable consumer characteristics, and where it
can be demonstrated that the characteristic being added will result in a measurable
improvement in the nutritional status of the target population.54 These authors
insist that golden rice meets the first two characteristics, and that the third is
under exploration: “However, it is important not to be overly cautious, in view of
the potentially enormous benefits to the poor.”55 Although they take seriously the
lesson of QPM, they ignore that of thiamine-enriched rice, which is that the most
sustainable approach of all to a specific nutrition deficit may be dietary
diversification (in this case, with carotene-rich fruits and vegetables). There is
also the matter of licensing and intellectual property rights: is access to patented
techniques without cost or at low cost sustainable, if farmers move out of the
category of subsistence farmers and into the category of producing and selling
improved grain for cash? Golden rice, by this point in time, has involved some
seventy IPRs claimed by some thirty-two different proprietors. With the
prodding of public-sector “humanitarians,” the finished product that has employed
these techniques will be made available to poor subsistence farmers who desire it.
But their economic categorization, as well as the production and trade patterns
which dictate the freedom to operate within different countries under international
trade laws, are not static.56 This continuously shifting landscape creates another
hurdle for nutritionally enhanced plant production, distribution, and consumption,
and for the sustainable contribution of particular GMOs to human nutrition.

Beyond golden rice, scientists predict that advances in molecular biology, of
cloning, and understanding of genetic transformation and gene-expression
mechanisms should soon make it possible to engineer the pathways for many of
the thirteen essential vitamins into plants. Better understandings of essential-
mineral uptake processes by plants should also allow scientists to produce GMOs
that extract iron from the soils more efficiently. But even if these super-nutrient-

54. Swapan Datta & Howarth E. Bouis, Application of Biotechnology to Improving Nutritional Quality of
55. Id. at 451.
56. See Eran Binenbaum et al., Int’l Food Policy Research Inst., South-North Trade, Intellectual Property
Jurisdictions, and Freedom to Operate in Agricultural Research on Staple Crops, (Dec. 2000), Discussion Paper,
at http://www.ifpri.cgiar.org/checknames.cfm/epdt1p70.pdf?name=epdt1p70.pdf&direc=d:\webs\ifpri\
divs\epdt\dp\papers.
rich varieties can be produced in the laboratory, questions remain about how they will perform in the fields and kitchen, and who will pay for the crop developments. Up until the current time, the companies that claim intellectual property rights over genes and genetic-transformation constructs have exacted restrictive licensing agreements from all users. During the years 1999 and 2000, extremely negative publicity surrounding the possible risks (without offsetting demonstrable benefits) of GMOs caused some turnaround in company policies. The Rockefeller Foundation, the Swiss Federal Institute of Technology, and the European Community Biotech Program announced that, like the green-revolution rice varieties, golden rice would be freely available to farmers in developing countries. A commentator in the journal *Science* undoubtedly voiced the sentiments of the donors as well as the companies when she concluded: "One can only hope that this application of plant genetic engineering to ameliorate human misery without regard to short-term profit will restore this technology to political acceptability."

D. Are GMO Production and Processing Methods Sustainable?

Seeds produce in relation to available moisture, soil nutrients, and pests. Although crops can be genetically modified to raise yields in water-stressed, alkaline, or pest-infested environments, investment in the modification of environmental resources are obvious complements or alternatives to the genetic modification process. Improved non-biological technologies also carry agronomic costs that are addressed at the next stage by plant breeders, who design, for example, salt-tolerant crop varieties for saline environments, which result from poorly drained irrigation works, and herbicide-tolerant varieties that can withstand the chemicals designed to kill weeds nourished by extra fertilizers and moisture.

Sustainability also has a biodiversity dimension. First, how many different crops or byproducts are in the agroecosystem? Is the agroecosystem monocropped or multi-cropped, or are crops grown in rotation? As attention shifts to modification of single crops, and especially those that can tolerate herbicides, these likely will marginalize production of grain legumes other than soy, and also remove all of the other edible matter, including edible herbs, that are parts of traditional field systems and diets. Second, how many varieties of any

particular crop species are sown? Will a narrow range of seed materials render crops vulnerable to widespread blights, such as that which afflicted genetically uniform plantings of corn that contained T-cytoplasm in 1970, or blight-vulnerable potatoes that wiped out European tubers the century before? Third, what impact does the cropping process have on relay crops or subsequent crops within the field system? Early discussions about the promise of biotechnology applied to potatoes, a crop increasingly sown between seasonal crops of grains in south Asia, anticipated the design of innovative agroecosystems in which relays of crops could take advantage of residual chemicals, biological residues, and moisture of preceding seasons.

Crop by crop, it is necessary to track which are the key productivity constraints, and what are the most appropriate approaches to overcoming these constraints. Over multiple seasons and generations of crop plants, what are their environmental and monetary costs? What will be the costs of continually updating seeds, to keep up with coevolution of pests and the evolving ecological constraints of cropping conditions, and who will invest in monitoring and responding to these situations? Also, how will new seed varieties be produced, updated, and marketed? Will they be hybrids that will have to be sold anew every year, which also means farmers will be unable to save seeds for planting?

Additional questions surround the changing significance of special-trait GMOs in food systems. What are some processing or nutritional quality characteristics that can change a plant species’ cultural significance and economic value, as did mechanical ginning, and then the elimination of gossopol, which transformed the place of cotton in the food chain? Increasingly, businesses find diverse uses for the most important crops, which are multifunctional: they provide food, feed, sometimes fuel, and additional industrial products. The disposal or utilization of the non-edible plant parts raises or lowers the economic value and calculated production costs of a crop, while breeding for a particular component changes its place in the food system, ecosystem, and economy. High-oil, specialized quality oil, or more digestible soybeans fill different roles in the diet, and appeal differently to specialized sectors in consumer markets. Maize varieties that contain starch adjusted to meet requirements for feed, fuel, or industrial products such as road "salt" or plastics fill different roles in farmer, state, and national economies and play a different role in the food

58. For a recent discussion, see Ellen Messer, *Potatoes (White)*, in *THE CAMBRIDGE WORLD HISTORY OF FOOD*, supra note 22, at 187.
system. These factors, and particularly the non-food uses of what are principally food crops, need to be considered when describing and projecting the contributions of GMOs to future world food systems, diets, and nutrition.

Will only a few improved (or specialized) varieties come to dominate agriculture over entire regions and leave plants, farmers, and food systems vulnerable to proverbial blight?\(^9\) In the early 1970s, U.S. plant breeders and seed production and distribution channels were able to respond rapidly, restore production, and remove the threat of additional genetic vulnerability. But how common will such rapid response be in developing countries, to which seed purveyors are aggressively marketing a few key varieties in major plant crop species?

It is this institutional context for monitoring and responding to risk that troubles scientists and policy makers, who foresee that reductions in biodiversity and varietal choices, stemming from the marketing of GMOs, will reduce farmers' control over production choices in developed as well as in developing countries. Although the international agricultural system has made available gene banks to store and protect genetic diversity in major crop species, there must be plant breeding institutions ready to use them. Crop choices also shape the uses of water, energy, and soils, which are likely to be in increasingly short supply. The main issue is not whether GMOs will or will not reduce pollution and pest damage or enhance production with greater economies of scale, but rather who will make the decisions on what crops and cropping methods will be promoted and available. By leaving the choices to the private sector, governments remove incentives for anyone to work on poor people's crops or agro-ecological ("alternative") farming systems. There are few examples of legislators asking the public to ponder how each GMO product might contribute to sustainability before approving its commercial release, or how GMOs might contribute to the human right to food, or, as some reframe the issue, "the capabilities of people to feed themselves."\(^60\)

Ideally, GMOs should be developed to fill niches in agricultural production that will benefit small farmers and in nutrition that will benefit economically

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59. This is a reference to the Great Potato Famine, caused by fungal blight in the mid-19th Century, and more recently, the Southern Corn Blight of 1970 in the United States.

60. Norway provides one such example. The government following public guidance has demanded that agricultural biotechnology (ABT) "product developers demonstrate how the product will contribute to sustainable development," although how to define "sustainable development" remained under discussion. Messer & Dudnik, supra note 2, at 43.
disadvantaged consumers, thereby contributing to social sustainability. But so far there is little evidence that developments in GMOs, dominated by the private sector, will help those who are currently food insecure generate greater effective demand (desire plus ability to pay) to improve their situation. Opponents argue that the level of public attention to GMOs, and the demands for public investments in biotechnologies so that developing countries do not fall behind, remove research and extension from agroecological, people-centered approaches, which are more likely to benefit small-scale producers in the short and long term.

This clash between monocrop, high-tech seed, cash chemical-intensive agriculture on the one hand, and diversified, farmer-controlled, management-intensive agriculture on the other, is at the heart of the agroecological critique. Private research by and large does not support the latter, and public research cannot support both. Herein lies the contradiction of this position: the best way to make new technologies serve the people is by having more control over these technologies in the public sector.

**Conclusion**

Will GMOs deliver nutritionally adequate food? The answer to this question depends on which questions one is really addressing and on the institutional and product-development choices being made at the present time.

Whether GMOs prevent absolute and relative food shortage and ensure nutritionally adequate food supplies will depend on what people are eating—which grains, roots and tubers, or other crops, and how they are combined into cropping systems. The answer also depends on what kinds of diets people are eating, whether diets are basic (vegetarian) or enriched to a smaller or greater degree with animal products that are produced from grain-fed animals.

Whether GMOs will improve access to food for those who otherwise lack land, wage, or social-security entitlements will depend on the political-economic contexts into which GMOs are introduced. These contexts include land reform, fair wage structures, labor's right to organize, and the technological and economic choices made by governments about the mix of farming or other livelihood systems to promote. They also include the micro- and macro-economic policies of governments that define a country’s competitiveness, shape farmers’ crop choices, and influence comparative advantage for the producers, the agricultural sector, and the country as a whole. The economic context also
involves the role of the private and public sectors in influencing these choices and developments.

Whether GMOs will improve the nutritional values of food and help eliminate malnutrition will depend on what crops are targeted. In the case of products tailored to the nutritional needs of vulnerable groups in developed countries, the answer is a qualified “yes,” in that companies such as DuPont and Monsanto have specialty products, with special starch and fat compositions, in the pipeline. How soon they will be delivered probably will depend less on technology than on cultural attitudes. 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.

In sum, the simple answer to the opening question, “are GMOs the best way to ensure nutritionally adequate food?” is “no” because food insecurity is a problem of inadequate access, and GMOs promise to do little to remedy that problem. GMOs that protect food crops against losses due to pests might improve productivity, lower production costs, and decrease the food prices paid by consumers, thereby increasing food access for the poor. In developing countries, GMOs potentially could increase productivity and reduce losses to pests for small farmers who rely on their own food production for much of their diet. But such products and institutions will require investments in the crop species, characteristics, and adaptive breeding so that the traits are available in the varieties that these farmers grow. For sustainability, this requires significant control of the seed supply and constant monitoring of performance, with ready availability of updated varieties as pests co-evolve to overcome resistance. So far, most attention has been devoted to developing the right seeds, and very little to the additional steps of how seeds will be produced and distributed with adequate quality controls or how they might function in the field. The economics of cash crops suggest that specialty items, such as flowers, may be a better route to improve income and access to nutritionally adequate food than some food crops. But impacts on farmers’ effective demand will depend on additional factors, such as farmer control over land, relative negotiating strength in contract farming, and the place of particular crops in the world market. These in turn depend on terms of environment and trade, again features that go beyond GMOs per se.
These outlooks, scenarios, and projections are instructive. They remind us that the factors influencing the advance and acceptance of GMOs are as much social as technological. The public may yet shut down GMO production, particularly if developers cannot demonstrate that they contribute to sustainable development, however that may be defined. Sustainability questions are not only environmental, but also economic and social: what are the contributions of the products, and does society need them at all? Curiously, these social and institutional contexts of sustainability are comparatively underexplored, and more reactive than pro-active. For those seriously concerned about sustainability, food security, and progress in human development, an informed, open, pro-active public discourse on GMOs is imperative.