The Future of Food

Since the known benefits of biotech foods outweigh the uncertain risks, the precautionary principle supports the use of such foods.

BY INDUR M. GOKLANY

In the 1980s, the precautionary principle migrated from its European roots to the international environmental scene. By 1992, it was ubiquitous: it appeared in the Rio Declaration, the United Nations Framework Convention on Climate Change, and the Convention on Biological Diversity (CBD). These precedents ultimately spawned the CBD's January 2000 Cartagena Protocol on Biosafety, which uses the principle as a basis for assessing the risk of international transfer, handling, and use of genetically modified organisms. This protocol is considered a major victory for the precautionary principle and its advocates.

A popular formulation of the precautionary principle is the Wingspread Declaration: "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 established scientifically."

This principle has been interpreted by many to require—as precautionary measures—policies to curb technologies that science cannot prove to be absolutely safe. Specifically, it has been invoked to justify a ban on research, development, and deployment of genetically modified (GM) crops.[1] This application of the precautionary principle acknowledges the public health and environmental risks that a ban might reduce but ignores other risks that a ban might generate or prolong. Therefore, while the operation might be successful, the patient might die. Moreover, the principle provides no guidance in situations where actions such as a ban on GM crops could simultaneously generate uncertain benefits and uncertain harms.

To avoid counterproductive "precautionary" policies, I propose a framework for applying the precautionary principle. This new approach provides a way to evaluate policies that might result in ambiguous outcomes because the harms might offset, in whole or in part, the benefits of GM crops. Using this framework, the precautionary principle can be used to answer a variety of difficult questions in the debate over GM crops. For example, do the public health and environmental benefits of GM crops exceed their harms? Considering the wide range of consequences of banning such crops, would the precautionary principle, in fact, justify such a ban? Finally, would a ban be consistent with the stated aims and objectives of the CBD and the Biosafety Protocol?[2]

Competing Uncertainties

This framework consists of a set of hierarchical criteria to rank various threats based on their characteristics and likely consequences.

The first criterion is *human mortality*: the threat of death to any human, no matter how humble, outweighs similar threats to members of another species, no matter how magnificent. Moreover, the other nonmortal threats related to human health—such as blindness, stunting, additional days of sickness, or lowered educational attainment—should take precedence over threats to the environment, although exceptions might be made based on the nature, severity, and extent of the threat. This is the *human morbidity* criterion. These two criteria can be combined into the *public health* criterion.

Additional criteria must be considered if an action under consideration results in both potential benefits and harms to public health or

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the environment. These other criteria include:

■ **The immediacy criterion.** All else being equal, more-immediate threats should be given priority over threats that could occur later. This criterion is justified because people tend to partially discount the value of lives that might be lost in the distant future.[3]

■ **The uncertainty criterion.** Threats of harm that are more certain should take precedence over those that are less certain if their consequences otherwise would be equivalent.

■ **The expectation value criterion.** Other things being equal, precedence should be given to threats with higher expectation values. For example, actions resulting in fewer expected deaths should be preferred over those resulting in more expected deaths.

■ **The adaptation criterion.** To the extent technologies are available to cope with, or adapt to, an impact, then that impact ought to be discounted.

■ **The irreversibility criterion.** Greater priority should be given to outcomes that are irreversible, or likely to be more persistent.

Weighing the Benefits

Before making any decisions regarding new technologies, including GM crops, we first need to assess the harms and benefits associated with the technologies with respect to public health and the environment.

■ **Environmental benefits.** Diversions of land and water to agriculture are the greatest threats to the world's biological diversity.[4] Worldwide, agriculture accounts for 38 percent of global land area, 66 percent of water withdrawals, and 85 percent of consumptive use of water—water that is no longer available for immediate use elsewhere.[5] Agriculture also affects biodiversity through water pollution and atmospheric transport—for example, by releasing excess nutrients, pesticides, silt, and greenhouse gases into the environment. Land-based agricultural activities also affect aquatic, coastal, and marine systems.

In the future, the world's biggest environmental challenge will be to meet the growing demand of a larger and wealthier population for food, nutrition, fiber, timber, and other natural resource products while conserving habitat and biodiversity. Biotechnology could be key to reconciling these opposing goals.

Worldwide, there will be a tradeoff between increased agricultural productivity and increased land conversion for the next 50 years. Assuming that the human population will be 8.9 billion in 2050 and that crop production per capita will grow at the same rate between 1997 and 2050 as it did between the early 1960s and late 1990s, and if conventional agricultural productivity increases 1 percent per year between 1997 and 2050, then 325 million hectares (800 million acres) of forests or other habitat will have to be converted to new cropland. That's a 21.5 percent increase over the 1,510 million hectares of existing cropland.[6] This would inevitably increase pressure on terrestrial biodiversity. Given existing, but unused, opportunities to increase productivity, such increases are plausible with conventional agriculture.

However, if biotechnology increases productivity by 1.5 percent per year—corresponding to a cumulative 30 percent increase in productivity by 2050 due to biotechnology alone—then agriculture could return 98 million hectares of current cropland to nature. An increase to 2 percent per year would return 422 million hectares.

Numerous GM crops, in various stages between research and commercialization, could make such gains plausible. GM crops could be bioengineered to tolerate poor climatic and soil conditions, including acidic soils, drought, and high salinity levels, conditions which prevail in many developing countries. For instance, 43 percent of tropical soils are acidic, and one-third of the world's irrigated land has been lost to salinity.[7]

GM crops can also make agriculture more environmentally sustainable. Higher productivity leads to less cropland, less soil erosion, less silt, and less carbon in the water and the atmosphere. GM crops could also be bioengineered to fix their own nitrogen, increase nitrogen and phosphorus uptake from the soil, and resist pests. Such crops would lower environmental loading of nutrients, pesticides, and nitrous oxide.

In the United States, for example, in 1999, cultivation of corn genetically modified to express the *Bacillus thuringiensis* (*Bt*) gene—which repels pests without the need for chemical pesticides—reduced pesticide usage 400 thousand hectare-treatments.[8] Production also increased by 2.3 billion liters, equivalent to the output of 200 thousand hectares.[9]

Bioengineering could also enhance feed to reduce phosphorus in animal waste, lowering its runoff into streams, lakes, and other waters. Similarly, in 1999, the use of the herbicide resistant "Roundup Ready" soybean reportedly lowered pesticide usage by 8 million hectare-treatments, while simultaneously increasing yields and facilitating no-till cultivation, a very effective method of containing erosion.[10]

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TABLE 1. Public Health Problems That Could Be Alleviated Using GM Rather Than Conventional Crops

Problem	Current Extent (Year)	Likelihood that GM crops would reduce problem
Undernourishment	825 million people (1994-1996)	very high
Malnutrition	6.6 million deaths per year in children under 5 years (1995)	very high
Stunting	200 million people (1995)	high
Iron-deficiency anemia	2 billion people (1995)	high
Vitamin A deficiency	260 million people (1995)	high
Ischemic & cerebrovascular diseases	2.8 million deaths per year in HIC (1998); 9.7 million deaths per year in LIC/MIC (1998) (includes those due to smoking)	moderate
Cancers	2.0 million deaths per year in HIC (1998); 5.2 million deaths per year in LIC/MIC (1998) (includes those due to smoking)	moderate

Note: HIC = high-income countries; LIC = low-income countries; MIC = mid-income countries.
Source: World Health Organizaiton, *The World Health Report 1999*. See endnote 2.

■ **Public health**. Sufficient food is the first step to a healthy society.[11] Despite unprecedented progress in the last half century, 825 million people still suffer from hunger and malnourishment, and more than 2 billion people suffer from various micronutrient deficiencies. Worldwide, GM crops could reduce public health problems arising partly or wholly from deficiencies in the quantity or nutritional quality of food, from malnutrition to heart disease.

Cumulatively, in 1995, hunger and malnutrition were responsible for 6.6 million, or 54 percent, of the deaths worldwide in children younger than five years, stunting in 200 million children, and clinical xerophthalmia—a condition of the eye, caused primarily by a lack of vitamin A, that causes thickening and drying of the conjunctiva and cornea and could lead to blindness—in about 2.7 million people.[12]

Bioengineering can increase the quantity as well as the nutritional quality of food, as exemplified by "golden rice," which is rich in beta-carotene, a precursor to vitamin A. Crossed with another bioengineered strain, such rice could help reduce vitamin-A and iron-deficiency-related deaths and diseases globally.

Bioengineered crops can also help battle the so-called "diseases of affluence." In 1998, these diseases—heart disease, hypertension, and cancer—accounted for 4.8 million deaths in high-income countries, and 14.9 million deaths in the low- and middle-income countries. GM crops that could reduce this toll include low-fat soybeans, higher-protein rice, tomatoes with increased antioxidant content, potatoes with higher starch than conventional potatoes, and vitamin-fortified fruits and vegetables.

Finally, pest-resistant GM plants can—by reducing the amount, toxicity, or persistence of pesticides—reduce accidental poisonings and other health problems affecting farm workers.

Weighing the Costs

In spite of the estimated benefits of deploying bioengineered crops, there has been much hue and cry from concerned scientists and the public about the risks inherent in this new agricultural technology. Some fear that GM crops may encourage pesticide-resistant insects and superweeds, hurt beneficial insects, and harm human health.

■ **Environment**. Perhaps the most familiar environmental concerns about GM crops center on pest-resistant and herbicide-tolerant crops. One risk is that target pests will become resistant to toxins produced by pest resistant GM crops, such as *Bt* corn or *Bt* cotton. However, recent studies from Arizona, Mississippi, and Australia indicate that bollworm, for instance, did not increase its resistance to *Bt* toxin produced by a GM *Bt* cotton.[13]

Conventional strategies to deter pest resistance to conventional pesticide, such as maintaining refuges of non-*Bt* crops, crop rotation, and expanded monitoring, can be adapted for GM crops.[14] Other strategies include developing crops with more than one toxin gene acting on separate molecular targets and inserting the bioengineered gene into the chloroplast—the structure in the cells of green plants that is critical for photosynthesis. These alterations allow more *Bt* toxin to be expressed, so that more of the pest insects die and fewer live to develop resistance.[15]

Another source of risk is that *Bt* plants could harm nontarget species. Studies in non-field conditions show higher mortality in Monarch butterflies fed with leaves dusted with pollen from *Bt* corn. Studies have also shown that the larvae of green lacewings that ate corn borers fed with *Bt* corn were more likely to die.[16] However, whether—and

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the extent to which—these studies represent real world conditions is debatable.[17]

The U.S. Environmental Protection Agency recently concluded that the weight of evidence indicates no hazard to wildlife from the continued registration of *Bt* crops, and *Bt* corn is unlikely to cause widespread harm to Monarchs.[18] More importantly, the inadvertent effects due to airborne dispersal of pollen or leakage into the soil through the roots of *Bt* crops could be virtually eliminated by bioengineering genes into the chloroplast rather than into nuclear DNA.

Bioengineered herbicide or pest tolerant crops might also escape into wild relatives leading to "genetic pollution" and creating "superweeds." Since that would defeat the very justification for such GM crops, farmers and GM seed vendors have substantial economic incentives for preventing the creation of herbicide-tolerant superweeds and, failing that, keeping such weeds in check.

Gene escape is possible if GM crops are planted near wild relatives. However, the most common GM crops—soybeans and corn—have no wild relatives in the United States. Also, conventional breeding has rendered many crops—corn and wheat, for example—"ecologically incompetent," that is, the hybrid forms in common use can't easily reproduce in natural conditions and are unlikely to cross pollinate with other species. A 10-year British study of four herbicide-tolerant or pest-resistant GM crops—oilseed rape, corn, sugar beet, and potato—shows that they are no more invasive or persistent in the wild than their conventional counterparts.[19] This study also provides reassurance that "superweeds" perhaps can't invade natural ecosystems, and confirms that such GM plants have no competitive advantage in natural systems. Moreover, had any herbicide-tolerant or pest-resistant weeds begun to spread, available crop management techniques—such as applying an herbicide to which the GM plant had not been engineered to be resistant—could have been used to control them. Finally, the chances of gene escape from GM to non-GM crops can be further reduced by maintaining a buffer between the two crops.

Of course, gene escape could be limited with greater certainty if the GM plants were engineered to be sterile or prevented from germinating, using, for instance, "terminator technology." An alternative approach would be to insert the gene into the chloroplast, which would preclude spread through pollen or fruit, as well as prevent root leakage.[20]

Finally, there is a concern that, in the quest to expand yields, herbicide-tolerant and pest-resistant GM plants would work too well and further simplify agricultural ecosystems, decreasing biodiversity.

■ **Public health.** Some fear that the new genes inserted into GM plants could be incorporated into a consumer's genetic makeup. However, plant and animal DNA has always been a part of the daily human diet. In fact, an estimated 4 percent of human diet is composed of DNA, which is naturally present in meats and plants.[21]

Another concern is that GM crops could trigger allergies in unsuspecting consumers. One to 3 percent of adults and 5 to 8 percent of children in the United States suffer from food allergies, and each year food allergies cause 135 fatalities and 2,500 emergency room visits. But GM foods can and have been tested, and most importantly rejected, prior to commercialization for their allergic potential. In fact, the precision of bioengineering could be used to render allergenic crops non-allergenic.[22]

Finally, antibiotic resistant markers used to identify whether a gene has been successfully incorporated into plants could accelerate the trend toward antibiotic-resistant diseases. But this threat is slight compared to that due to overuse of antibiotics in livestock feed and by humans.[23] Moreover, alternative markers have been devised for many crops, with more in the offing.

Applying the Principle

Clearly, there are risks associated with using or not using GM crops. The framework presented earlier offers a way to evaluate actions that could result in uncertain costs and uncertain benefits. Ideally, each criterion should be applied separately to the public health and to the environmental consequences of using or not using GM crops. However, since there are variations in the severity, certainty, and magnitude associated with the various competing costs and benefits regarding each of these sets of consequences, I will apply several criteria simultaneously.

■ **Public health.** The human population could increase 50 percent between 1998 and 2050, and with it undernourishment, malnutrition, and their consequences, assuming global food supply increases by a like amount and all else remains equal. Thus, unless food production outstrips population growth significantly over the next half century, billions of people in the developing world may suffer from undernourishment, hundreds of millions may be stunted, and millions may die from malnutrition. Based on the sheer magnitude of people at risk of hunger and malnutrition and the

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degree of certainty attached to their public health consequences, limiting GM crops by limiting the rate at which food production can expand, will almost certainly increase death and disease, particularly among the world's poor.

By contrast, the negative health consequences of ingesting GM foods—for example, the effects due to ingesting transgenes—are speculative. Other risks are relatively minor in magnitude, such as a potential increase in antibiotic resistance. Some are speculative and relatively minor, such as increased incidence of allergic reactions. Moreover, as noted, many of these impacts can be contained, if not eliminated.

Thus, based on the uncertainty, expectation value, and adaptation criteria applied either singly or in conjunction, GM crops must be favored over conventional or alternative agricultural production systems. Hence, the precautionary principle requires that we continue to research, develop, and commercialize—with appropriate safeguards, of course—those GM crops that would increase food production and generally improve nutrition and health, especially in the developing world.

Some have argued that many developed countries are awash in surplus grain, and they do not need larger harvests.[24] But reducing those surpluses would harm public health in developing countries, which currently import about 10 percent of their cereals. Without these surpluses, food supplies would be lower and food prices would be higher, as would undernourishment, malnutrition, and associated health problems. Developing countries' deficits are expected to rise because of future population and economic growth and, possibly, global warming. Therefore, developed countries' surpluses will continue to be critical for future food security in developing countries, just as they are today.

The above argument against GM crops also assumes that they will provide little or no public health benefits to developed countries. But GM crops are also being engineered to combat diseases of affluence, which claim 4.8 million lives annually in the developed countries. Even a small reduction in these numbers due to GM crops would translate into relative large declines in the death toll. Moreover, the health benefits of "golden rice," for instance, do not have to be confined to developing countries. Thus, even in developed countries, the potential public health benefits of GM crops ought to outweigh in magnitude and certainty the speculative health consequences of ingesting GM foods.

Another argument against developing GM foods is that hunger and malnutrition are rooted in maldistribution and unequal access to food and not in food shortages; therefore, there is no compelling need for biotechnology.[25] This argument tacitly acknowledges that GM crops would boost quantities more rapidly than would conventional agriculture. More importantly, GM crops do not decrease access. In fact, by increasing production, they would lower prices, which would increase access, particularly for the lower rungs of society.

One factor contributing to poor food distribution is crop spoilage. But various GM crops could increase shelf life, reducing spoilage and wastage. Moreover, nutritional quality is just as important as food quantity, and GM foods can enhance the former far easier than conventional agriculture.

Bioengineered crops do not have to be the sole solution for hunger and malnutrition. It is sufficient that they contribute to the solution and are among the most efficient solutions. If the argument that there is sufficient food is truly compelling, then it should be equally valid for arguing against increases in production using conventional technologies. Perhaps, then, developing countries like India and Bangladesh should forego increasing agricultural productivity altogether, and should focus only on improving access and distribution. For obvious reasons, no one makes this argument.

■ **Environment.** Regardless of the level of demand, GM crops would increase yields per unit of land used. And higher yields mean less land for mankind, and more for the rest of nature.

Moreover, reduced land demand for mankind means lower land prices and socioeconomic opportunity costs for sequestering land for conservation and preservation, which would facilitate conservation of species and biodiversity in the wild—a major goal of the Convention on Biological Diversity.[26]

Also, by reducing amounts of cropland, fertilizers, and pesticides, GM crops would reduce soil erosion and releases of nutrients, pesticides, carbon, and nitrous oxide emissions into the environment.

Compare these tangible ecological benefits of GM crops to the more speculative environmental benefits of limiting pest-resistant and herbicide-tolerant GM crops even without factoring in the environmental costs of conventional farming. Assuming GM crops actually do harm nontarget pests and weeds more than conventional farming practices, banning GM crops may increase the diversity of the flora and

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fauna, but this is an uncertain benefit. In addition, the possibility of gene escape to weeds and non-GM crops is also uncertain.

Hence, with respect to the environmental consequences of the use or nonuse of GM crops, one must conclude, based on the uncertainty and expectation value criteria, that the precautionary principle promotes cultivation of GM crops. This would conserve the planet's habitat, biodiversity, and carbon stores and sinks, provided due caution is exercised, particularly with respect to herbicide-tolerant and pest-resistant GM crops.

It may be argued that although gene escape to the environment is highly unlikely, under the irreversibility criterion GM crops ought to be banned. However, increased habitat clearance and land conversion resulting from such a ban may be at least as irreversible, particularly if it leads to species extinctions.

Finally, the precautionary principle supports using terminator-type technology because it would minimize the possibility of gene transfer without diminishing any of the public health or environmental benefits of GM crops.

Speed with Caution

The precautionary principle has often been invoked to justify a prohibition on GM crops.[27] However, while this justification touts the potential public health and environmental benefits of a ban on GM crops, it ignores any harm caused by delaying or foregoing benefits that GM crops would bring.

Worldwide, more than 800 million people suffer from hunger and undernourishment, and more than 2 billion suffer from malnutrition each year. As a result, millions suffer death and disease annually. But in comparison to conventional crops, GM crops, in fact, would increase the quantity and nutritional quality of food supplies. This should reduce mortality and morbidity rates worldwide. And by increasing productivity and reducing chemical inputs, GM crops would increase land available for the rest of nature and reduce global pollution by fertilizers, pesticides, and carbon. Thus, GM crops would also better protect habitat, biological diversity, water quality, and the current climate than would conventional agriculture.

Hence, contrary to conventional environmental wisdom, the precautionary principle—properly applied, with a more comprehensive consideration of the public health and environmental consequences of a ban—argues for a sustained effort to research, develop, and commercialize GM crops, provided reasonable caution is exercised during testing and commercialization of the crops.

In this context, a "reasonable" precaution is one whose public health and environmental benefits are not negated by the harm incurred due to reductions or delays in enhancing the quantity or quality of food or the health of the environment. Any such harm to public health would be disproportionately borne by the poorest and most vulnerable segments of society.

The Convention on Biological Diversity is dedicated to conserving biodiversity, preferably through conservation in the wild.[28] But a GM crop ban is more likely to magnify threats to biodiversity, and reduce land and water available for such conservation. Hence, such a ban would be directly counter to the CBD's very reason for existence, and that of any subsidiary agreements such as the Biosafety Protocol.

Finally, slowing down commercialization of GM crops would, by reducing the future quantity and quality of food available, arguably abridge the "right to a standard of living adequate for the health and well-being...including food, clothing" and the "inalienable right to be free from hunger and malnutrition" as specified in the Universal Declaration of Human Rights and the Universal Declaration on the Eradication of Hunger and Malnutrition, respectively, thereby violating Article 10 of the Declaration on Human Rights Defenders, which states that "No one shall participate, by act or failure to act where required, in violating human rights and fundamental freedoms."

While it might be a mistake to go full steam ahead on GM crops, it might be an even larger mistake to stop them in their tracks. The wisest policy would be to go as fast as possible while keeping a sharp lookout, and staying on the track to improvements in human and environmental well-being.[29]■

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NOTES

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