Feeding the World in the 21st Century: The Role of New Science and Technology[1/]

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Introduction

It is a pleasure to participate in the dedication ceremonies of this marvelous new research facility of the Delaware Biotechnology Institute. I am now in my 57th year of continuous involvement in agricultural research and production in the low-income, food-deficit developing countries. I have worked with many colleagues, political leaders, and farmers to transform food production systems and overcome the doomsday predictions of the 1960s of impending worldwide famine. As a result of these efforts, food production has more than kept pace with global population growth. On average, world food supplies were 24 percent higher per person in 1998 than they were in 1961 and real prices are 40 percent lower (Pinstrup-Anderson *et al*, 1999). But there is no room for complacency on the food production and poverty-alleviation fronts.

It took some 10,000 years to expand food production to the current level of about 5 billion gross tonnes per year. By 2025, we will have to nearly double this amount again. This cannot be done unless farmers across the world have access to current high-yielding crop-production methods, as well as the new biotechnological breakthroughs that can increase the yields, dependability, and nutritional quality of our food crops.

What Can We Expect from Biotechnology?

In the last 20 years, biotechnology based upon recombinant DNA has developed invaluable new scientific methodologies and products in food and agriculture (ACSH 2000). Recombinant DNA products are commonly known by the misleading and unfortunate term, genetically modified organisms or GMO, as if genetic modification of organisms is something new. Recombinant DNA methods have enabled breeders to select and transfer single genes, which has not only reduced the time needed in conventional breeding to eliminate undesirable genes, but also allowed breeders to access useful genes from other distant species. So far, these gene alterations have conferred producer-oriented benefits, such as resistance to

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pests, diseases, and herbicides. But many consumer-oriented benefits, such as improved nutritional and other health-related characteristics, are likely to be realized over the next 10-20 years. The majority of agricultural scientists—myself included—anticipate great benefits from biotechnology in the coming decades, in helping to meet our future food, feed and fiber needs.

In animal biotechnology, bovine somatatropin (BST) is now being widely used commercially to greatly increase milk production. We can also expect GM vaccines against diseases for farm animals, many of which can be delivered via their feed, thus reducing the expense of traditional veterinary treatments. Such technology can be especially significant for poor farmers in low-income countries, where infrastructure is primitive and veterinary care is very weak.

One challenge that has intrigued me for many years is to develop domestic livestock with resistance to the Trypanosomiasis, a disease transmitted by the tste tste fly. This disease has restricted the spread of domestic livestock in much of subtropical sub-Saharan Africa, resulting in shortages of meat, milk, and animal traction. However, it is known that the giant Eland, a wild "herd" species of antelope that once was widespread, and the dwarf West African N'Dama cattle, are highly tolerant to this disease. Eventually through biotechnology, it is likely that either the genes that confer tolerance to Trypanosomiasis in these species can be transferred in to more productive cattle, sheep, and goats, or the giant Eland could be domesticated and bred by selection for docility. Such breakthroughs could have tremendously positive economic and nutritional impacts in one of the poorest and most food-insecure regions of the world.

I also understand that through recombinant DNA techniques, considerable progress has been made in developing fast-growing, meaty GM salmon by incorporation of a gene from another species in controlled fish farms. Given the stagnation of global fish catches in recent years, such developments offer new opportunities through aquaculture to increase production.

In plants, transgenic varieties and hybrids of cotton, maize and potatoes, containing genes from ***Bacillus thuringiensis,*** which effectively control a number of serious insect pests, are now being grown commercially on large areas in the United States, Argentina, Canada, and China. The use of such varieties will greatly reduce the need for insecticide sprays and dusts. Considerable progress also has been made in the development of transgenic varieties or hybrids of cotton, maize, oilseed rape, soybeans, sugar beet, and wheat, with tolerance to selected herbicides. This can lead to a reduction in overall herbicide use through much more specific interventions and dosages. Not only will this lower production costs; it also has important environmental advantages.

Food crops with greater tolerance of abiotic extremes will benefit both irrigated and rainfed areas. In the case of irrigated cereal crops, we will be able to achieve "more crop per drop" through designing plants with reduced water requirements. Genotypes will also be developed that can better withstand greater climatic challenges, such as heat, drought, and cold. For example, corn (maize) and beans are very sensitive to light frosts. However, through genetic engineering cold/frost tolerance is likely to be incorporated into these important food crops, thus broadening their ecological adaptation and permitting early spring planting for better utilization of available soil moisture.

Virus diseases have for centuries caused heavy losses in animal and crop production. Within the past decade, varieties of tomato, pepper, cucumber, potato, squash, and papaya have been developed, and are being grown commercially, with coat-protein mediated resistance to one or more important virus diseases. These breakthroughs, using biotechnology transgenic gene-splicing techniques, reduce pesticide use and crop losses, while improving crop quality (Beachy et al, 1990). Virus-resistant varieties of sugar beets, rice, barley and wheat are now in various stages of field evaluations.

There are also hopeful signs that we will be able to improve fertilizer use efficiency as well. For example, by genetically engineering wheat and other crops to have high levels of glutamate dehydrogenase (GDH), preliminary evidence suggests that yields can be increased 20-30 percent with the same amount of fertilizer (Smil, 1999).

I would like to share one dream that I hope scientists will solve in the not-too-distant future. Among all the cereals, rice is unique in its immunity to the rusts (***Puccinia*** spp.) All the other cereals—wheat, maize, sorghum, barley, oats, and rye—are attacked by two to three species of rusts, often resulting in disastrous epidemics and crop failures. Much of my scientific career has been devoted to breeding wheat varieties for resistance to stem, leaf, and yellow rust species. After many years of intense crossing and selecting, and multi-location international testing, a good, stable, but poorly understood, type of resistance to stem rust was identified in 1952 that remains effective worldwide to the present. However, no such success has been obtained with resistance to leaf or yellow rust, where the genetic resistance in any particular variety has been short-lived (3-7 years). Imagine the benefits to humankind if the genes for rust immunity in rice could be transferred into wheat, barley, oats, maize, millet, and sorghum. At long last, the world could be free of the scourge of the rusts, which have led to so many famines over human history. This breakthrough would permit scientists to focus more time on many of the other diseases that affect cereal crop yield and production, and which heretofore have been neglected, because of the need to be "fighting fires" caused by the ever-changing rust pathogens.

On another front, bread wheat has superior dough for making leavened bread and other bakery products due to the presence of two proteins—gliadin and glutenin. No other cereals have this combination. Imagine if the genes for these proteins could be identified and transferred to the other cereals, especially rice and maize, so that they, too, could make good-quality unleavened bread. This would help many countries, and especially the developing countries in the tropics, where bread wheat flour is often the single largest food import.

Finally, it is also important to mention the growing potential of science to improve the nutritional quality of our food supply. The development, using conventional plant breeding methods, of high-yielding quality protein maize (QPM) varieties and hybrids, which carry much higher levels of two essential amino acids—lysine and tryptophan—took more than two decades of painstaking research work. Adoption of these QPM materials is now spreading in Africa, Asia and Latin America and stands to bring substantial nutritional benefits to poor consumers, as well as livestock.

In the future, through biotechnology, we will see further nutritional "quality" enhancements in the cereals and other foods at a much faster rate. Recently, the transfer of genes to increase the quantity of Vitamin A, iron, and other micronutrients contained in rice can potentially bring significant benefits for millions of people with deficiencies of Vitamin A and iron, causes of blindness and anemia, respectively. Unfortunately, there has been far too much "hype" surrounding this research effort, accompanied by many exaggerated claims. Notwithstanding this criticism, I do agree that significant benefits are likely to be forthcoming from such lines of research in the not too distant future.

Standing Up to Anti-Science Zealots

Despite the formidable opposition in certain circles to transgenic crops, commercial adoption by farmers of the new GMO crops has been one of the most rapid cases of technology diffusion in the history of agriculture. Between 1996 and 1999, the area planted commercially to transgenic crops has increased from 1.7 to 39.9 million hectares (James, 1999). Preliminary estimates for 2001 are that the area planted to transgenic plants could increase to 43-44 million hectares.

While there have always been those in society who resist change, the intensity of the attacks against GMOs by certain groups is unprecedented, and in certain cases, even surprising, given the inherently environmentally friendly nature of the technology. The opposition to the Bt modified corn, for example, seems especially ironic. The common bacterium ***Bacillus thuringiensis*** (Bt) has been used for half a century by organic growers to control caterpillars. Rachel Carson, in her provocative 1962 book, ***Silent Spring***, was especially effusive in extolling the virtues of this bacterium as a "natural" insecticide. But the anti-GMO activists have decried the incorporation of the Bt gene into the seed of different crops, even though this can reduce the use of insecticides and is harmless to other animals, including humans.

One of the arguments against the use of Bt crops that I find especially ludicrous is that widespread use may lead to mutations in the insects that will render the bacterium ineffective. Genetic mutation and recombination is the driver of evolution, which is an ongoing process. Without it, we would all probably still be slime on the bottom of some primeval sea. Inevitably, insect resistance to a particular strain of ***Bacillus thuringiensis*** will break down, and this is why we need to sustain dynamic research programs—both for conventional and biotechnology breeding—to continue to develop varieties with new combinations of genes that ensure that adequate resistance in maintained. This is the essence of successful plant breeding programs.

As I see it, there are essentially two major aspects of the recombinant DNA debate in agriculture. One deals with safety of GMOs, per se, and the other with issues of access and ownership over the various GM products that are produced. Part of the consumer concern about GMO safety curiously revolves around whether introducing "foreign DNA" into our food crop species is "natural" (with the implied value judgment that this is "unnatural" and thus an inherent health risk). Since, all living things—including food plants, animals, and microbes—contain DNA, I would ask how recombinant DNA can be considered foreign? Next, defining what constitutes a "foreign gene" is also problematic, since many genes are common across many organisms. Almost all of our traditional foods are products of natural mutations and genetic recombinations, which were greatly accelerated, beginning about 8,000-10,000 years ago by Neolithic woman. With the domestication of our food crop species came the dawn of agriculture and the beginning of human civilization.

From a regulatory point of view, at least three Federal agencies in the United States provide scrutiny over the safety of GMOs—the US Department of Agriculture, which is responsible for seeing that the plant variety is safe to grow; the Environmental Protection Agency, which has special review responsibilities for plants that contain genes that confer resistance to insects, diseases, and herbicides; and the Food and Drug Administration, which is responsible for food safety. These agencies are charged with ensuring that GMOs, within reasonable risk levels, are safe to grow by farmers and be utilized by consumers. But we must also realize, there is no such thing as "zero biological risk." It simply doesn't exit.

There is no scientific information to date to substantiate that GMOs are inherently hazardous. They have been used for 25 years in pharmaceuticals employing recombinant DNA, with no documented cases of harm attributed to the genetic modification process. So far, this is also the case in GM foods. This is not to say that there are no risks associated with particular products. There certainly could be. But we need to separate the methods by which GMOs are developed—which are not inherently unsafe—from the products, *per se*, which could be, for example, when certain toxins or allergens are introduced.

There certainly have been some mistakes in the GMO certification process. The most glaring recent example, in my opinion, was the "restricted" approval by EPA of a Bt corn hybrid, Starlink, for use only as an animal feed because of possible allergenic reaction that this strain of Bt might have in humans. Approval for restricted end-use was given by EPA, knowing full well that marketing channels did not exist to segregate corn destined for animal feed from corn destined for human consumption. As a result, this corn got into various corn chips and taco shells. This lapse in common sense, allowed the anti-biotechnology pressure groups to have a field day, and undermined public confidence in the U.S. regulatory process.

However, the argument that GM foods warrant labeling because the insertion of recombinant DNA into food is a form of chemical and biological contamination is a spurious one, since all living things contain DNA. Thus, common sense should prevail in the issue of labeling. Obviously, it does make sense for GM foods to carry a label if the food is substantially different from similar conventional foods. This would be the case if there is a nutritional difference, or if there is a known allergen or toxic substance in the food. But if the food is identical to the regular versions of the same food, what would be the utility? To me, such labeling would entirely undermine its central purpose, which is to provide any useful nutritional or health related information to allow consumers to make an "informed choice."

A second controversial aspect of GMOs is concerned with ownership and access to the new products and processes. Since most of GMO research is being carried out by the private sector, which patents its inventions, issues of intellectual property rights in life forms and farmer access GM varieties must be seriously addressed. Traditionally, patents have been granted for "inventions" rather than the "discovery" of a function or characteristic. How should these distinctions be handled in the case of life forms? How long, and under what terms, should patents be granted for bio-engineered products? The high cost of biotechnology research is also leading to a rapid consolidation in the ownership of agricultural life science companies. Is this desirable? I must confess that I harbor serious concerns. All these issues are matters for serious debate, both within the scientific community and also in the political arena.

During the past two decades, U.S. support to the public sector national research system has slowly declined, while support for international agricultural research has dropped so precipitously to border on the disastrous. If these trends continue, we risk losing the broad continuum of agricultural research organizations—from the more basic to the more applied and practical—needed to keep agriculture moving forward. Strong public sector research programs also are needed to provide dynamic research environments to train new generations of scientists. They also have a role to play, I believe, as "neutral scientific brokers" so that farmers and consumers do not become hostages to private sector research monopolies.

One important characteristic of publicly funded research is that historically the information and products that it produces have tended to be quite freely available, not only to U.S. scientists, but also to the international scientific community. The benefits of this scientific sharing have been enormous, and have gone both ways.

Permit me to give just two examples. The advent of international germplasm exchange and testing began in the early 1950s in wheat, in response to a devastating stem rust epidemic in North America. At the time, all U.S. and Canadian wheat germplasm was susceptible to a new race of stem rust, called 15 B. The situation was critical. In search of resistant germplasm, the USDA appealed to other research programs in the Americas for access to possible resistant materials. The Mexican Government-Rockefeller Cooperative Agricultural Program with which I was associated, as well as several national agricultural research programs in South America, responded rapidly, agreeing to exchange a broad range of their best early- and advanced-generation breeding materials, and to test these materials at many locations. Out of this initial effort, new sources of stem rust resistance were identified that have held up to this day. Indeed, no stem rust epidemics have occurred in the Americas in nearly 50 years.

A new institutional innovation was in the making, which become the hallmark of the international centers supported by the Consultative Group on International Agriculture (CGIAR), such as CIMMYT, with which I have been associated since its establishment. International germplasm testing networks broke down the psychological barriers that previously had isolated individual breeders from each other, and led to the introduction of enormous quantities of new and useful genetic diversity. It became accepted policy that individual breeders could use any material from these international nurseries, either for further crossing or for direct commercial release, as long as the original source of the germplasm was recognized. This led to the accelerated development around the world of new high-yielding cultivars, with much higher levels of disease and insect resistance, and ushered in a golden age in plant breeding.

Another major contribution of international agricultural research cooperation has been the germplasm collection efforts of native landraces pioneered in maize by the Mexican Government-Rockefeller Foundation agricultural program during the 1950s, with subsequent assistance from the U.S. National Academies of Science. Today, the CGIAR seed banks contain much of the genetic diversity of maize food crops species. These germplasm collections are held in trust for the benefit of humankind. Without them, much of the biodiversity in many food crop species might have been lost by now. However, because of intellectual property rights, access to these germplasm collections is becoming increasing problematic.

Today, it is becoming increasingly difficult, often because of national restrictions driven by intellectual property rights considerations, for the international centers to freely exchange breeding materials and germplasm with other research institutions. I understand that the International Potato Center (CIP) in Peru, now has difficulty in obtaining permission from the national government to send the germplasm it develops to collaborating research institutions outside the country.

Given the trends in privatization of intellectual property rights in food crop species, and the growing restrictions on the free exchange of germplasm, one wonders whether the resource-poor farmers of the developing world will be able to gain access to the GM products (or even conventionally bred varieties, for that matter) in the future? Of course, reasonable regulatory frameworks need to be put into place in the developing countries on the testing and use of GMOs, both to protect their people and environments. In addition, legal frameworks are needed that protect intellectual property rights. Obviously, GMO pirating will not encourage private companies to sell their products in developing countries.

But the private life science companies must also give serious consideration to pricing issues, and in particular, to the extent to which they are willing to give price concessions so that poor farmers can also benefit from the new GM products In addition, will these companies be willing to share some of their expertise with national research institutions—often of a public character—to assist local scientists to use biotechnology to work on crops and agricultural problems in which the large transnational companies have little interest?

These are complex issues, and ones to which I don't have clear answers. What I can say, however, is that hopefully a sufficient sense of goodwill and humanity will exist in current and future generations so that new forms of public-private collaboration come into being to ensure that all farmers and consumers worldwide will have the opportunity to benefit from the new genetic revolution.

Closing Comments

Over the past 30 years, we all owe a debt of gratitude to the environmental movement in the industrialized nations, which has led to legislation to improve air and water quality, protect wildlife, control the disposal of toxic wastes, protect the soils, and reduce the loss of biodiversity. In almost every environmental category far more progress has been made than most commentators in the media are willing to admit (Easterbrook, 1996). Why? I believe that it's because "apocalypse sells."

Sadly, all too many scientists, many of whom should (and do) know better, have jumped on the environmental bandwagon in search of research funds. When scientists align themselves with anti-science political movements, such as many of those in the anti-biotechnology crowd, what are we to think? When scientists lend their names and credibility to unscientific propositions, what are we to think? Is it any wonder that science is losing its constituency? We must maintain our guard against politically opportunistic, charlatan scientists, like the late T.D. Lysenko, whose pseudo-science in agriculture and vicious persecution of anyone who disagreed with him, contributed greatly to the collapse of the former USSR.

Thirty-one years ago, in my acceptance speech for the Nobel Peace Prize, I said that the Green Revolution had won a temporary success in man's war against hunger, which if fully implemented, could provide sufficient food for humankind through the end of the 20th century. But I warned that unless the frightening power of human reproduction was curbed, the success of the Green Revolution would only be ephemeral. I now think that the world has the technology—either available or well advanced in the research pipeline—to feed on a sustainable basis a population of 10 billion people. The more pertinent question today is whether the farmers and ranchers of the world will be permitted to use it?

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