BIOTECHNOLOGY: OPPORTUNITIES AND ADJUSTMENTS

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Biotechnology, a set of research techniques, has wide application in American scientific laboratories in the 1980s. Biotechnology is used in the basic and applied research aiming at the development of new products for, among others, medicine, food processing and agriculture. After the outburst of enthusiasm followed by a period of unfulfilled expectations, biotechnology has quietly contributed to a steady research progress in recent years. It continues to attract investment capital in the private sector. More money is being allocated to biotechnology by public sector institutions. For example, USDA competitive grants program allocates about $20 million for biotechnology research in the fiscal year 1987 (Crawford).

Biotechnology is being applied, among others, in the improvement and development of agricultural commodities. The information about advances in agricultural biotechnology is rather sketchy. A considerable capital investment needed to start a biotechnology laboratory and the desire to secure a return on research results are reasons for limited public knowledge about the timing of the commercial application of biotechnology in agricultural production. The public has a chance to learn about the potential marketability of some cultivars from the content of permissions for field testing issued by authorized federal agencies, conference reports, and, occasionally, press information.

The lack of information about the nature of agricultural biotechnologies makes an economic analysis of its application difficult. Results of such an analysis, including changes in the input use, volume and location of production, changes in social and geographical income distribution etc., are sought by the decision makers responsible for research funds allocation.

An agricultural economist faced with the task of providing a forecast of the future biotechnology impacts has to develop a data base which can be used in formulating a prediction. The objective of this study is to identify agricultural biotechnologies that are the most likely to be developed in the future, requirements for their optimal application, opportunities that they are going to create for producers and consumers, and to present what possible adjustment processes may be caused by the wide use of agricultural biotechnology.

Definition of Biotechnology and Questionnaire Content

Biotechnology is defined as "the science of the agricultural production processes involving the use of cells and tissues from higher organisms where, in both cases, the action could not be initiated or continued with the application of the classical agricultural breeding techniques." A survey of researchers working in the area of agricultural biotechnology was used to gather information about the possible timing of the commercial application of biotechnology.

The world-wide survey was conducted by mail and included 21 agricultural biotechnologies applicable in production of six crops: corn, wheat, soybeans, sorghum, rice, and potatoes. The choice of crops in the questionnaire was determined by their importance for the U.S. and world agriculture. The detailed information collected through the survey took into account the timing of the commercial application, the expected yield change, potential changes in input use and the probabilities of a developed cultivar. A detailed report on the survey and preparation results was made available (Florkowski and Hill). This paper interprets the results.

Expected Commercial Application of Selected Biotechnologies

The set of eight biotechnologies for corn, soybeans, and wheat that were assigned the highest subjective probability of being commercially available is presented in Table 1. Six of the eight technologies listed are identical for the three crops. The probabilities of adoption associated with those six technologies are similar except for changing amino acid balance and bacteria resistance. This indicates that manipulating the genetics of plant amino acid balance has its own distinguished characteristics for each specie. Also, bacterial diseases, different for various plants, require crop-specific approach in developing resistance.

Improved resistance of herbicides as well as insect and fungus resistance are expected in corn, soybeans, and wheat within a relatively short time period. That result is supported by expectations of some scientists with regard to other crops. For example, a herbicide-resistant rapeseed is predicted to be marketed in 1989 and should be followed quickly by other plants (Herbicide, Nitrogen Genes Keep Biotechnica Growing). The only biotechnology that is very crop specific and can be developed relatively soon is a new Rhizobium strain used in soybean production.

The list of biotechnologies assigned the highest subjective probabilities of being applied commercially (Table 1) includes also the development of corn with altered lipid composition and heat-tolerant wheat. The latter, however, was assigned the smallest probability by survey respondents from all the improvements included in Table 1.

Results presented in Table 1 suggest that the development of the improved cultivars using biotechnology will progress faster in corn and soybean breeding if measured by the magnitude of probabilities. The range of the assigned probabilities of the commercial application of biotechnology is the narrowest in the case of soybeans and the widest for wheat.

Among the six least likely crop improvements developed through biotechnology (Table 2) four were named for each of the three crops. Plants capable of fixing nitrogen through an autosufficient process were, in general, assigned very low probabilities of becoming commercially available. This is particularly true about soybeans which currently depends on Rhizobium for nitrogen supply. Similarly, plants with suppressed photorespiration, enhanced photosynthesis, and resistant to insects in storage have little chances of being available in the foreseeable future.

Changes in Yield and Input Use

Changes in yield and input use in crop plants that can be obtained using biotechnology relatively soon are also very promising in terms of the expected yield change and, in some cases, the direction in input use. Corn, soybeans, and wheat resistant to insects would yield 10 percent, 8 percent, and 11 percent, respectively (Table 3). Strong, positive impact on yields can be expected from other improvements in disease resistance. Herbicide tolerance will increase yields less in the case of corn and wheat cultivars, but the increase in soybean yield is going to be substantial. Two quality altering technologies, plants with higher protein content and changed amino acid balance will decrease yields.

The results of the survey suggest that the improvement of disease resistance through biotechnology application will lower significantly the use of pesticides and labor in production of corn, soybeans, and wheat. In the case of pest-resistant wheat and insect resistant corn, the required fertilizer application rates would have to be increased.

Disease-resistant cultivars seem to be among the most promising agricultural technology improvements that can be developed using biotechnology. They have the potential of considerable yield increase while lowering the application of pesticides. Their commercial introduction could lead to a lower average cost for producers, although it will depend on the seed price of new cultivars. Private development and ownership of proprietary rights to a new cultivar may likely result in a higher seed price than in the case of public ownership.

Increased tolerance of herbicides would lead to a higher herbicide use in wheat production and higher application of phosphate and potash fertilizers on soybean fields while cultivars with a higher protein content, in general, would have lower yields. Their nutrient needs will increase causing higher fertilizer application. This is also true, as suggested by the survey results, about corn and wheat with changed amino acid balance.

Regulatory Issues

Since the implementation of of the Plant Variety Protection Act in 1970, the interest in plant breeding among private firms has widened significantly. The possibility of obtaining a patent for a new improved cultivar made investment in a breeding program attractive. That also strengthened economic incentives through which some breeding programs are guided in particular, by the size of possible revenues from seed sales. The survey of scientist working in the area of agricultural biotechnology provided information indicating that all technologies assigned a high probability value (Table 1) are likely to be patentable. A patent on an improved cultivar could lead to a monopoly and a possible high seed price. But, as some scientists indicate, the progress in biotechnology is so fast that there are new ways to "get around" a patent (Biotech's Bewildering Tangle of Patents).

The Plant Variety Protection Act provides a qualified breeder with the certificate guaranteeing rights to exclude others from reproducing, selling, or using the reproduced plants. The applicant must submit an accurate description of a new cultivar that includes physical characteristics distinguishing it from earlier developed plants. Genetic engineering techniques allow making changes in plant organisms without developing distinguishable physical characteristics.

Therefore, some lawyers suggest the adoption of isozyme analysis in identifying cultivars (Coronado). Isozymes are multiple-form enzymes performing catalytic functions in an organism. Since they are included in the genetic code of a plant, they can be identified.

Another legal issue hindering the process of developing cultivars using biotechnology are the imprecise regulations guiding the issue of permissions for the field tests. Small groups of environmentalists have effectively blocked several attempts to conduct tests of cultivars. Recently, it was urged that cooperation among environmentalist, industry, and the government could provide an acceptable solution concerning tests of agricultural biotechnology (Crawford, 1986b; Krupp).

Opportunities Created by Agricultural Biotechnology

Cultivars, developed using biotechnology by private or public sector, provide the world, the United States, the Southeast, and the State of Georgia with new opportunities. Higher yields associated with improved cultivars increase the possibility of more stable and abundant food supply for the world. With predictions of continuing increase of the world population biotechnology can contribute to growing food needs. Although the production and distribution of food is influenced by other factors, for example price policy, credit supply, and marketing system, none of them can be fully used if the available cultivars produce low yields. Some experts fear that without further yield improvement the impression of food abundance will disappear within the next two decades (Mellor).

Food supplies larger than the quantity demanded are likely to lower the market price for feed and food grains as well as oilseed crops. Many countries with the most acute food shortages have also limited funds for the importation of food and a lower price may enable them to purchase larger quantities. Consequently, the chances for alleviating the world hunger can be enhanced. In addition, because some of the new cultivars will be more nutritious (e.g. more desirable amino acid balance) the diet deficiencies of the people in different parts of the world can be eliminated.

Feed grains with better nutritional qualities developed using biotechnology will increase livestock and poultry production, particularly in areas where commercial feed is used. Due to improved quality and larger volume of grains, meat and dairy production can be expanded and add to the diversity that human diets often lack. In addition, cereals with more desirable nutrient composition will directly supplement currently consumed foods. Better fed populations can become more productive while enjoying healthier and longer lives. This relationship has been recognized and the World Bank is rapidly expanding lending for population, health, and nutrition projects (Policy Reform).

The development of disease-resistant cultivars is a likely scenario according to the survey results. It allows a considerable decrease and, in some cases, the elimination of pesticides. Pesticides are often a costly input that has to be applied on fields in the danger of insect infestation, spread of a fungus or other pest.

Benefits of eliminating pesticide use will likely be distributed in proportion to the pesticide application. Thus, regions with climate and natural conditions favorable for pest propagation may be able to obtain considerable gains by lowering application of pesticides. This will follow if resistance to the currently most common insects, bacteria, viruses, nematodes or fungi will be developed through biotechnology. The use of pesticides is concentrated in production of corn, cotton, and rice. Therefore regions where those crops are grown will likely be the first to reduce the application of pesticides.

In the United States, agriculture in southern regions should be able to gain more from lower pesticide use than regions with cooler climates. For example, in 1983 farmers in Kansas spent 3¢ per acre of planted wheat on insecticides and 85¢ per acre on herbicides. During the same growing season, wheat production in Georgia required farmers to spend 38¢ per acre on insecticides and 2.18¢ per acre on herbicides (FEDS Budget 1984). Disease resistance may also expand the cultivation of some crops to areas where they could not otherwise be economically produced.

A decrease in pesticide use due to improvements in disease resistance developed through biotechnology will find support among environmentalists. Pesticides increase crop yield through a short term elimination of diseases, insects and weeds. However, the long term effectiveness of pesticides has been questioned (Balk and Koeman; Tabashnik). One argument against the use of pesticides was their non-selective action. They were lethal both to disease causing pests as well as to natural predators. After the pesticides became ineffective, the altered balance of the agro-ecosystem often allowed pests to reproduce without natural competitors.

Another argument against the use of pesticides is the increasing number of reports about the acquired resistance to pesticides. Biotechnology introducing disease resistance to plants can ease the risk of negative effects of pesticide run-off.

However, some environmentalists oppose the introduction of biotechnologically developed cultivars to agriculture fearing unpredictable consequences. Some of their legitimate concerns have been related to the precise implementation of the existing biotechnology regulation with regard to laboratory procedures and field testing. Activity of a few environmentalists became an intensely discussed issue in scientific and business literature (for example: The Wall Street Journal, 1986a; 1986b; 1985c). Perhaps, this will lead to some cooperation between environmentalists and business in the area of minimizing negative impacts of technology application.

Disease resistant cultivars may lower the application of pesticides but some other improvements, for example plants with higher protein content, may require increased fertilizer use according to survey results.

With conventional methods of fertilizing, nitrogen often does not reach the plant but is leached or enters into chemical reactions with other elements. As much as one half of the nitrogen is lost (Power). Nitrogen run-off causes water pollution and becomes an environmental hazard. Phosphorus and potassium uptake varies from 5 to 25 percent, and 40 percent to 75 percent, respectively (Hauck and Koshino). Although part of the nutrients remaining in the soil is absorbed by following crops some is lost away due to erosion. It is possible that in the long run biotechnology will be able to solve the problem by increasing plant capabilities for nutrient uptake.

In the case of increased demand for nitrogen the price for that fertilizer will increase due to the production process dependence on non-renewable energy feedstocks. Both, phosphate and potash fertilizers also are based on natural resources that can be depleted. The scarcity of available deposits will be reflected in fertilizer price increases.

Higher input prices will increase costs and limit the expansion of production. If the demand for grains and oilseeds should increase faster than the production capacity, consumers will have to pay a higher price for food. A larger volume of synthetic fertilizers applied on crops will increase losses and the pollution of water.

Anticipating Adjustment Processes

New cultivars developed using biotechnology create new opportunities. In order to capture opportunities and avoid the negative effects of biotechnology it is necessary to anticipate adjustment processes. Characteristics of adjustment processes will include spatial, time, and economic factors. The physical size of the geographic area, affected by biotechnology, determines the spatial dimension in which the adjustment process will take place. In particular, the adjustment process will differ if global impacts are considered in comparison to impacts in the United States, the Southeast or Georgia. Furthermore, the adjustment processes will be stretched over time and they may be different in the short and the long run. Finally, the adjustment process triggered by the introduction of biotechnologically obtained cultivars will vary between macro- and microeconomic levels.

Agricultural biotechnology development is concentrated in several industrialized countries with the United States leading the group in terms of allocated funds and on-going research. But the actual commercial application of cultivars obtained through biotechnology may take place in another country simply because of the complicated regulatory process in the U.S. An indication of that trend is the field test of an animal vaccine, genetically engineered in America, conducted in New Zealand and Argentina.

The commercial introduction of new cultivars outside the United States may increase the competitiveness of other countries on the world grain market. American farmers, especially those operating in marginal agricultural areas, would loose revenue generated from exported crops. Consumers in the United States would likely have to pay a higher price for many foods.

The commercial application of biotechnologically developed crops, by farmers in the United States, before making them available to other countries, could result in the different sequence of adjustments. In global terms, it is likely to improve the competitive position of the United States. An increased grain supply and lower prices would concentrate the world feed grain supply in a few countries. The E.E.C. may have to increase their grain export subsidies, a move that can be prevented by the ability of the community budget to finance such a strategy. The long term outcome of the competition on the world grain market will depend on the production cost per unit of output and its relation to market price.

Within the United States, the introduction of corn and soybeans characterized by altered nutritional qualities and disease resistance may, in general, lead to concentration of feed grain production in the North Central Region (Florkowski and Hill). Acreage operated in areas of marginal importance for cereal production can be expected to decrease.

A larger supply of grain on the world market and its lower price can discourage the production in countries with less favorable growing conditions in the long run. A decrease in the domestic production would lead to a greater dependence on imported grains. Less developed countries have already become major outlets for the U.S. corn exports in the past decade (Henneberry and Kargbo). Some scientists project that the food deficit in developing countries will double or even triple by the year 2000 assuming the past trends in agricultural production and population growth will continue (Paulino; Mellor). Many countries, where the exchange reserves would not allow extensive grain purchases, will increasingly rely on food aid donors, especially as the possibilities of expanding cultivation onto new lands diminish (Newland).

Grain importing countries may suffer from economic and political destabilization if the grain in-flow is disturbed. This can be prevented by the biotechnological development of cultivars and microorganisms that will be adopted to farming conditions in different countries. An example of a potentially effective technology in combating the nitrogen fertilizer shortage, in some less developed economies, is Azolla use if nitrogen fixing capability of algae increases through biotechnology application. Currently available strains are not cost competitive with available substitutes (Rosegrant et al.) but may become useful if the annual nitrogen needs increase from the present 60 million tons to 160 million tons by the year 2000 (Recombinant DNA Safety Considerations).

Reallocation of feed and food grain production and the possible withdrawal of acreage from corn, wheat, and soybeans from operation may require adjustments. The withdrawn land can be planted with alternative crops. The significance of alternative crops for marginal agricultural areas may substantially increase. Other, non-farm use for fallowed land may have to be found. Replanting it with trees or recreational use are some of the possible solutions. As a result a decrease in erosion of top soil is possible.

Some of the rural communities that will experience a slowdown in agriculture without a corresponding development of other business are likely to decline in economic and social importance. For regions already suffering from the 1980s agricultural financial crisis, crops developed using biotechnology are not likely to provide any relief.

Adjustments following the commercial application of biotechnology are going to take place at the farm level as well. New input requirements and the possible wider choice of cultivars will stress the importance of decisions with regard to resource management. The access, collection, and analysis of the information about the characteristics of new cultivars will become crucial. An increased effort in familiarizing farmers with the new technology can be necessary.

The competitive structure of American agriculture was, in the past, a major force behind the desire to constantly increase production efficiency through adoption of new technology. New technology adoption is associated with, among others, changes in the quantity and type of inputs used, volume of production, market prices and commodity utilization. The commercial introduction of biotechnologically developed cultivars will alter the existing patterns of commodity production and distribution because new technology may eliminate the existing interregional comparative advantage in agriculture through changes in input application, yields and markets.

This article discussed only some opportunities and adjustments that can be expected from the commercial use of plant biotechnology. Recently Hansel summarized the possible achievements in animal biotechnology. His paper included a brief evaluation of some economic impacts. Food processing industry also becomes affected by biotechnology (Stipp). The complexity of the future outcomes demands further attention of researchers, and agricultural economists can contribute to the interdisciplinary evaluation of biotechnology impacts.

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Table 1. Biotechnologies applicable in corn, soybean, and wheat production assigned the highest subjective probabilities of being developed.

Corn		Soybeans		Wheat	
Technology	Probability	Technology	Probability	Technology	Probability
Amino acid balance	.82	Herbicide tolerance	.85	Herbicide tolerance	.81
Herbicide tolerance	.80	Rhizobium	.80	Fungus resistance	.75
Insect resistance	.76	Amino acid balance	.74	Insect resistance	.73
Protein content	.75	Insect resistance	.73	Amino acid balance	.69
Bacteria resistance	.72	Fungus resistance	.71	Protein content	.68
Fungus resistance	.72	Protein content	.69	Bacteria resistance	.63
Lipid composition	.63	Bacteria resistance	.69	Virus resistance	.62
Virus resistance	.62	Virus resistance	.68	Heat tolerance	.57

Table 2. Biotechnologies applicable in corn, soybean, and wheat production assigned the lowest subjective probabilities of being developed.

Corn		Soybeans		Wheat	
Technology	Probability	Technology	Probability	Technology	Probability
Photorespiration	.20	Autosufficient	.13	Rhizobium	.20
Photosynthesis	.33	Insects in storage	.26	Autosufficient	.25
Autosufficient	.34	Photorespiration	.33	Photorespiration	.26
Dry matter part.	.37	Storability	.35	Photosynthesis	.33
Insects in storage	.42	Photosynthesis	.40	Symbiotic	.35
Rhizobium	.43	Frost tolerance	.42	Insects in storage	.36

Table 3. Expected percentage change in yield due to application of biotechnology.

Corn		Soybeans		Wheat	
Technology	Yield change	Technology	Yield change	Technology	Yield change
Amino acid balance	0	Herbicide tolerance	10	Herbicide tolerance	6
Herbicide tolerance	4	Rhizobium	12	Fungus resistance	7
Insect resistance	10	Amino acid balance	-3	Insect resistance	11
Protein content	-3	Insect resistance	8	Amino acid balance	-4
Bacteria resistance	8	Fungus resistance	12	Protein content	-4
Fungus resistance	10	Protein content	1	Bacteria resistance	6
Lipid composition	2	Bacteria resistance	10	Virus resistance	9
Virus resistance	8	Virus resistance	7	Heat tolerance	8