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# Agricultural Biotechnology

## The Next "Green Revolution"?

Agriculture and Rural Development Department, World Bank
Australian Centre for International Agricultural Research
Australian International Development Assistance Bureau
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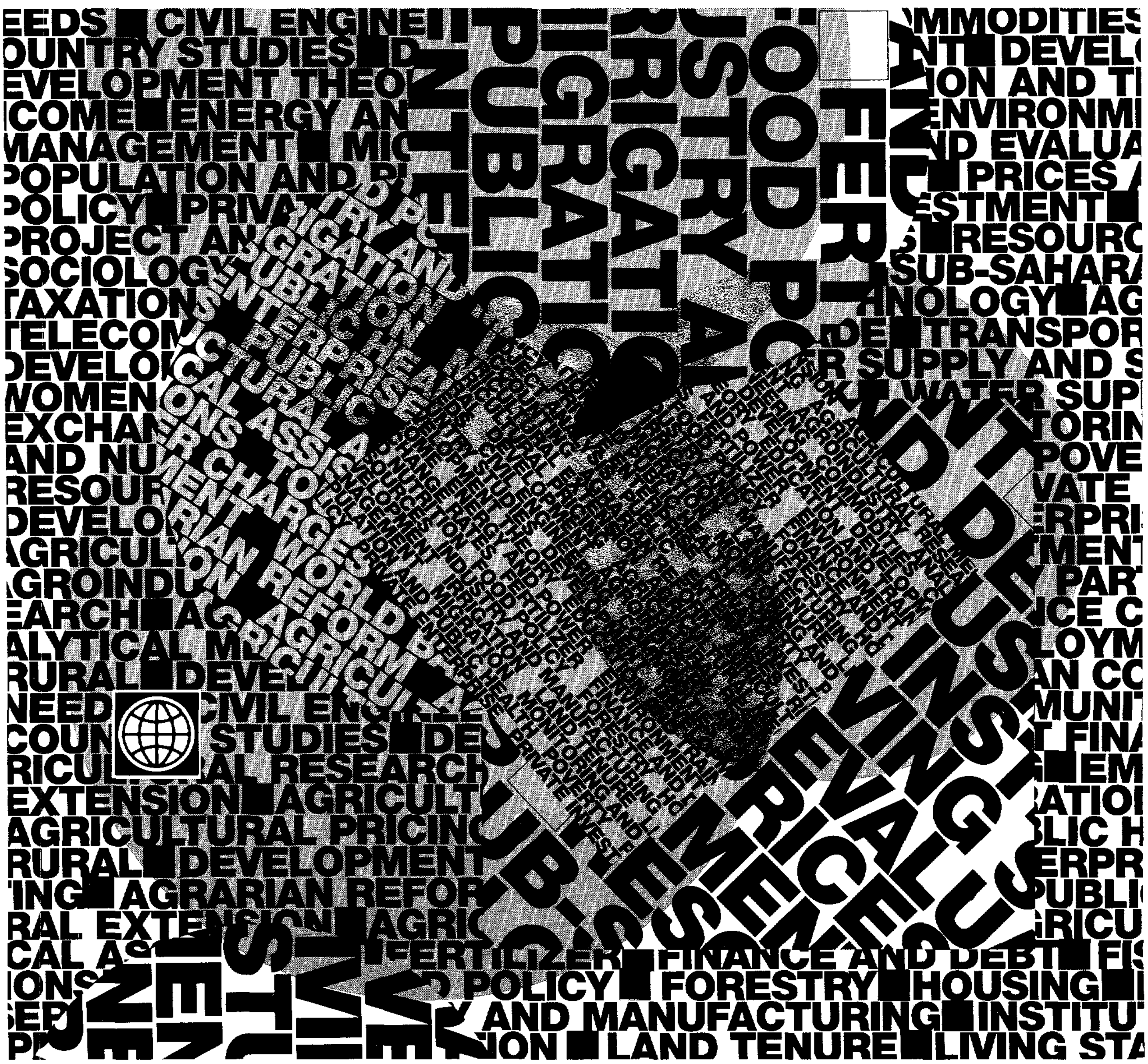

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## FOREWORD

Two of the world's most pressing agricultural problems are how to provide sufficient food for the increasing populations of the developing nations and how to preserve the genetic resources of plants and microorganisms. This base includes the genetic resources of plants and animals. New hope for solutions to these problems has been found in biotechnological research. This topic is of particular interest to the World Bank, which has long supported agricultural research through loans and credits to national programs and grants to international agricultural research centers, particularly those sponsored by the Consultative Group on International Agricultural Research. The Bank recognizes the continuing need for new technologies to accelerate agricultural development, especially for small farmers and poorer countries. The continuing success of the Bank's agricultural and rural development projects depends in part on the availability of such new technologies.

In 1988-89, the World Bank commissioned a study to assess the contribution that biotechnology might make to agricultural productivity, and to identify the socioeconomic, policy, and management issues that might impede its successful application. The study was co-sponsored by the World Bank, the International Service for National Agricultural Research (ISNAR), the Australian Centre for International Research (ACIAR), and the Australian International Development Assistance Bureau (AIDAB). Co-financing was provided by the Australian government, through AIDAB.

The study culminated in a seminar on agricultural biotechnology opportunities for international development, held in Canberra, Australia, in May 1989, prior to the midterm meeting of the CGIAR. Participants came from several countries of Asia, Africa, and Latin America; the international agricultural research centers; and several bilateral and multilateral development agencies. The preliminary findings were refined extensively in the light of the Canberra discussions and the results are presented in this report, organized around the following topics: the likely socioeconomic impact of biotechnology on world trade and economic development; opportunities for the application of biotechnology in crops, forestry, and livestock production; the issues connected with managing intellectual property; the need for risk assessment prior to the release of genetically engineered organisms into the environment; the opportunities for private/public sector cooperation; the future role of international centers in bringing the new biotechnology to their client countries; and the policy, educational, and management issues of concern to national agricultural research systems seeking to adopt biotechnological techniques. The report includes a summary of several country case studies initiated during the course of the study.

This report is a contribution to the policy dialogue among those concerned with the application of biotechnology to agricultural development.

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Agriculture and Rural Development Department, The World Bank

## ACKNOWLEDGMENTS

This technical report is based on a series of commissioned papers, papers prepared for the Canberra Seminar, country studies, and consultations concerning biotechnology conducted during 1988-89. The list of contributors is attached (Annex D). The valuable information they have brought to the study is gratefully acknowledged, as are the efforts of the three working groups that monitored the progress of the study. In addition, an advisory group met at the World Bank on 26-27 October 1989 to review the draft technical report and discuss its implications for the World Bank. The members of the advisory group were J. Barton, S. Best, P. Brumby, J. Doyle, V. Giddings, J. Peacock, A. Pritchard, and G. Persley. The present report reflects their recommendations.

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The project staff were encouraged throughout the course of the study by members of the co-sponsoring organizations: Mr. David Hopper, Chairman of the Consultative Group on International Agricultural Research; Mr. Michel Petit, and Mr. S. Barghouti, Agricultural and Rural Development Department, the World Bank; Dr. G. Rothschild, ACIAR; Dr. R. Dun, Dr. Richard Manning, Mr. Denis Fitzgerald, and Mr. Hilary Coles, AIDAB; Mr. Alexander von der Osten, Dr. Howard Elliott, and Dr. H.K. Jain, ISNAR and Professor J.R. McWilliam, Canberra. Their support and guidance are warmly acknowledged.

# CONTENTS

## EXECUTIVE SUMMARY

Modern biotechnology is a new aspect of biological and agricultural science which provides new tools and strategies in the struggle against the world's food production problems. The techniques for improving agricultural output range from novel approaches to cell and tissue culture to the genetic manipulation of biological material and have become available at a time of increasing concern about the environmental impact of agricultural expansion to new lands and the limitations of existing technologies. With strong support from the private sector, industrial countries have already invested considerable sums in testing these techniques and expect economically useful results by the turn of the century. In contrast, and in spite of their need for new production technologies as their populations continue to rise, and food remains in short supply, biotechnological research has barely begun in the developing countries. In the next 10 years, many countries will have to prepare for, and accept, technological change if they are to apply some of the new techniques for crop, forest, and livestock production already adopted in other countries. The steps being taken have been outlined in a 1988-89 study cosponsored by the World Bank, the International Service for National Agricultural Research (ISNAR), the Australia Centre for International Agricultural Research (ACIAR), and the Australian International Development Assistance Bureau (AIDAB). Its findings and recommendations are the subject of this report.

The great appeal of these techniques is that they can be used to improve the tolerance of both crops and animals to particular stresses, pests, and pathogens, and to increase the efficiency with which plants and livestock utilize limiting nutrients. They also hold out the promise of relieving the present biological constraints to higher yield. In countries where the new technologies are applied the result should be increased agricultural production, improved comparative advantage in the production of some commodities, new opportunities for the use of marginal lands and a reduced need for agrichemicals. A negative effect may be that some commodities produced for export in developing countries may be displaced by biotechnological products from the industrialized countries, but present evidence suggests that the weight of benefits would still strongly favor the application of biotechnology in the developing world. However it is likely to take several years before the new technologies could be developed to an effective level for use with the crops of economic importance in the developing countries: up to 5 years for potato, rapeseed, and rice; 5-10 years for banana/plantain, cassava and coffee, and 10 or more years for cocoa, coconut, oil palm, and wheat.

Support for biotechnology research in developing country agricultural research systems will be provided by the International Agricultural Research Centers but there are substantial differences amongst these in their current involvement in modern biotechnology. Most will need to develop substantive programs within the next decade, requiring the reallocation of some resources, the provision of additional targeted funds, new staff and placement of Center staff in other advanced institutions. It will also require legal and financial skills not commonly available at the Centers.

Socioeconomic Impact

The use of new technologies poses a particular challenge for poor countries and small scale impoverished farmers. These are most likely to be adversely affected by the social and trade changes that accompany modification in agricultural technology which frequently results in the displacement of small farmers by larger enterprises and the movement of centers of production to new areas in response to changes in comparative advantage. The dilemma is that without change in technology the balance between supply and demand for basic food commodities is likely to be upset, but acceptance of the technology will place additional burdens on the resource-poor small farmers.

The smaller and poorer countries will therefore require assistance in minimizing the social and economic costs of technological change. This could be through strengthening national research capacity, facilitating technology transfer (through appropriate licensing agreements and collaborative arrangements with established research laboratories), seeking unrestricted trade for export products, advice on research policy planning, and implementing measures that will recognize the needs of the smaller farmer, who will have the greatest difficulty adjusting to the new production circumstances.

Intellectual Property Management

The producers and sellers of new technology are mainly based in industrialized countries and will be reluctant to become involved in biotechnology ventures in developing countries, whether through direct investments or collaborative research agreements, unless some arrangements have been made to protect intellectual property rights. Consequently, countries seeking new technologies should become familiar with the role that patents or other protective devices can play in stimulating transfer of technology and local research. A clear understanding will also be needed of the cost involved, the license control to be provided under the protection and the limitations that might be placed on the franchise of a supplier, particularly with respect to the progeny of the plants and animals covered by the agreement.

Environmental Issues

The assessment of any risk that new technologies may pose to public health or environmental safety is an important issue. In many countries existing legislation is sufficient to regulate the use of most agricultural products likely to result from the applications of modern biotechnology. However guidelines are frequently needed to cover the handling of genetic engineering experiments and for assessing the risks that may be associated with the release and use of genetically modified organisms. These guidelines should be framed so as to complement and support existing regulatory agencies.

Studies from industrial countries indicate that the benefits from the use of the new biological technologies are likely to outweigh the risks, but urge that risk assessment be an integral part of the experimental process. Guidelines for risk assessment are now in use in several countries which can be applied to the assessment of the specific risks associated with release of genetically modified organisms into the environment.

Risk assessment in biotechnology requires national regulations covering the commercial use of biological materials, local biosafety committees to monitor experimentation on genetic engineering, and a national review body to regulate experiments and the release of genetically engineered organisms into the environment, and to monitor international experience and policies in this area.

Recommendations

International development agencies are already supporting a number of national agricultural research projects that include a substantial biotechnology component. The more technologically advanced developing countries should be encouraged to increase the rate of preparation of biotechnology programs requiring financial support.

Normal lending mechanisms of the World Bank and other agencies will continue to provide support to national biotechnology programs in technologically advanced developing nations. The poorer countries need grant funds to finance innovative collaborative research programs. To meet this need research consortia involving several donor countries and agencies would be established to promote research on the specific problems of the "orphan commodities" which are important only in the Developing World and which are largely ignored in the biotechnology programs financed in industrial countries.

Because of the rapidity of change in modern biotechnology and the accelerated rate at which new technologies for agricultural development are becoming available, international development agencies need to take positive steps to promote biotechnology. Applications for loans and grants for biotechnology programs from individual countries can be prepared and appraised using the existing procedures. In order to process these biotechnology projects efficiently development agencies will need access to biotechnology expertise. This is not readily available in existing staff or consultancy resources and new sources of advice appropriate to the issues of biotechnology will have to be obtained.

Individual countries will need impartial advice on the best way to integrate the methods of biotechnology into national research efforts and development programs. In order to ensure that the new programs are in line with national priorities and that public and private sector support will be forthcoming to make the resulting new products available to farmers, such advice should be made available before any steps are taken to seek external financing for new programs in this field.

Some countries will need assistance in the designing national biosafety procedures to monitor the release of genetically modified organisms into the environment. These guidelines should require any country seeking support for modern biotechnology from international development agencies to establish a national biosafety committee to regulate in-country genetic engineering projects.

Information should be made available to countries concerned with devising appropriate policies on intellectual property management. A careful study of the experiences gained under the variety of approaches to using and controlling patents and other licencing arrangements in the pharmaceutical and agricultural chemical sectors is required.

Further socioeconomic studies are required to assist in solving national problems resulting from changes in production technology, such as the potential displacement of traditional commodity exports by substitutes produced in industrial countries.

The novel features of biotechnology are of sufficient importance to merit the establishment by the international development agencies of innovative funding mechanisms and new systems for the processing of programs incorporating biotechnology. The design of such programs requires a policy dialogue amongst the international development agencies and aid-recipient countries as well as the major institutions working in modern biotechnology in the public and private sectors.

The vehicles through which the World Bank could provide increased support for agricultural biotechnology are; additional biotechnology components in national agricultural research projects supported by Bank loans and credits; new ventures involving the International Finance Corporation which would encourage the participation of the private sector in the commercial development of biotechnology; additional targeted grant funds for the International Agricultural Research Centers to increase their capacity in biotechnology research and to improve their ability to assist national agricultural research systems to acquire and adapt new technologies.

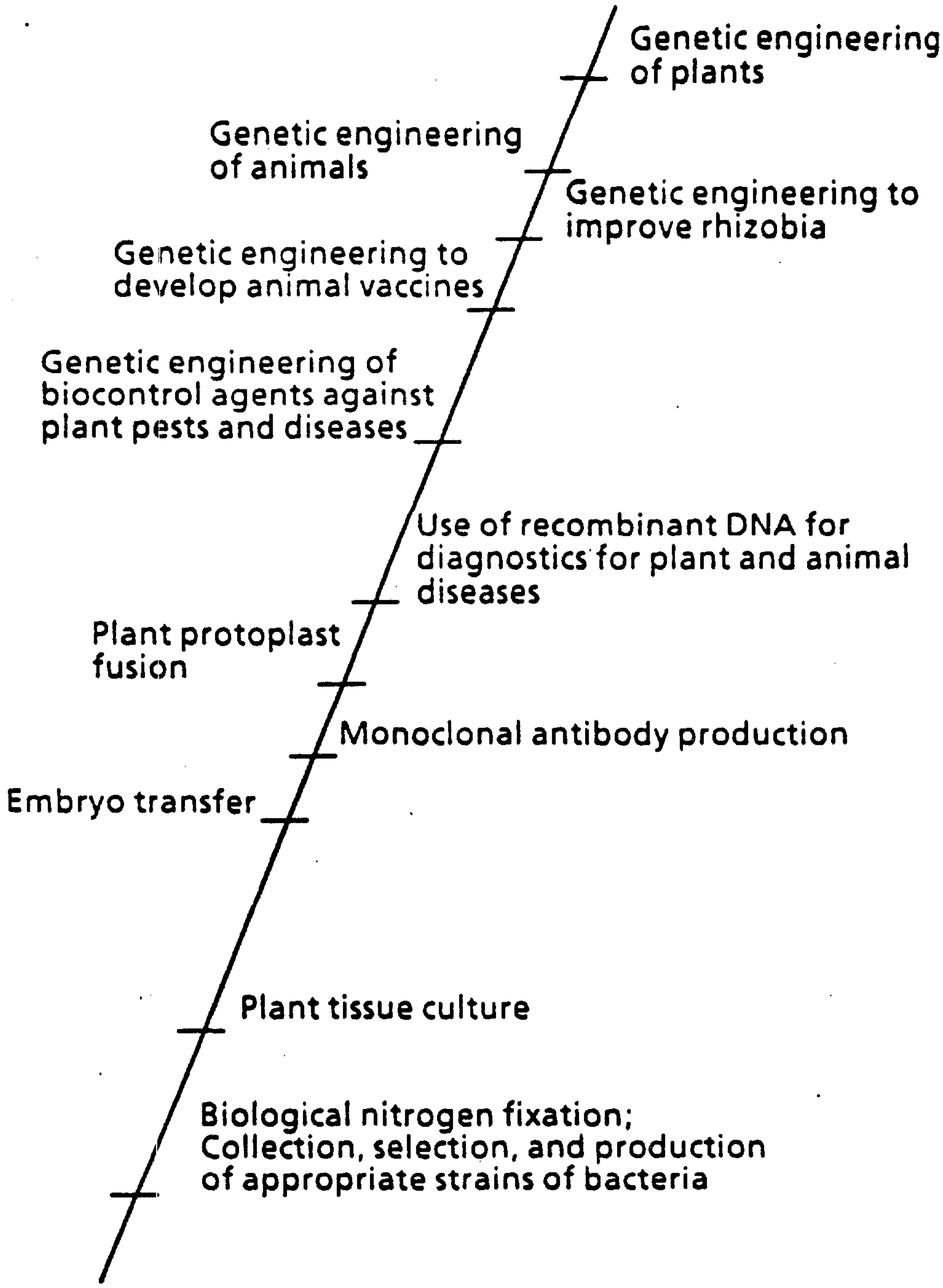
# CHAPTER 1. INTRODUCTION

The Office of Technology Assessment of the U.S. Congress has defined "Biotechnology" as "any technique that uses living organisms, or substances from those organisms, to make or modify a product, to improve plants or animals, or to develop micro-organisms for specific uses" (OTA, 1989). In this study, the term is applied in a broad sense to cover activities ranging from the long-established commercial use of living organisms (e.g., in brewing, the biological control of pests, and conventional animal vaccine production) to the more recent research on genetic engineering in animals and plants (Figure 1.1).

"Modern biotechnology" refers to recently developed techniques, notably those that make use of (1) recombinant deoxyribonucleic acid (DNA) technology enables the essential genetic material in cells, DNA, to be manipulated; (2) monoclonal antibodies which are used to detect individual proteins produced by cells; and (3) new cell and tissue culture technology which includes novel bioprocessing techniques and which have made the rapid propagation of living cells possible. Together, these three processes constitute the basis of genetic engineering, and can be applied to microorganisms, plants, and animals (see Annex A for glossary of terms used in biotechnology). A chronology of the development of the science of genetics and its evolution into modern biology is shown in Table 1.1.

The basic principle underlying genetic engineering is that genetic material (DNA) can be transferred from cells of one species to cells of another unrelated species, inserted into the chromosomes of that species and made to express itself in the recipient cells (For details on the principles of genetic engineering, see Persley and Peacock, 1990). This process offers considerable potential for manipulating and controlling genes in crops and livestock in ways that can lead to improved agricultural production.

Figure 1 Gradient of Biotechnologies




Source: Jones (1990)

Table 1.1 The evolution of the science of genetics, leading to modern biotechnology

| | |
|---|---|
| 1866 | Mendel postulates a set of rules to explain the inheritance of biological characteristics in living organisms. |
| 1900 | Mendelian law rediscovered after independent experimental evidence confirms Mendel's basic principals. |
| 1903 | Sutton postulates that genes are located on chromosomes. |
| 1910 | Morgan's experiments prove genes are located on chromosomes. |
| 1911 | Johannsen devises the term "gene", and distinguishes genotypes (determined by genetic composition) and phenotypes (influenced by environment). |
| 1922 | Morgan and colleagues develop gene mapping techniques and prepare gene map of fruit fly chromosomes, ultimately containing over 2000 genes. |
| 1944 | Avery, McLeod, and McCarty demonstrated that genes are composed of deoxyribonucleic acid (DNA) rather than protein. |
| 1952 | Hershey and Chase confirm role of DNA as the basic genetic material. |
| 1953 | Watson and Crick discover the double-helix structure of DNA. |
| 1960 | Genetic code deciphered. |
| 1971 | Cohen and Boyer develop initial techniques for recombinant DNA technology, to allow transfer of genetic material from one organism to another. |
| 1973 | First gene (for insulin production) cloned, using recombinant DNA technology. |
| 1974 | First expression in bacteria of a gene cloned from a different species. |
| 1976 | First new biotechnology firm established to exploit recombinant DNA technology (Genentech in USA). |
| 1980 | USA Supreme Court rules that micro-organisms can be patented under existing law (Diamond v Chakrabarty) Cohen/Boyer patent issued on the technique for the construction of recombinant DNA. |
| 1982 | First recombinant DNA animal vaccine approved for sale in Europe (colibacillosis). |
| | First recombinant DNA pharmaceutical (insulin) approved for sale in USA and UK. |
| | First successful transfer of a gene from one animal species to another (a transgenic mouse carrying the gene for rat growth hormone). |
| | First transgenic plant produced, using an Agrobacterium transformation system. |
| 1983 | First successful transfer of a plant gene from one species to another. |
| 1985 | US patent Office extends patent protection to genetically engineered plants. |
| 1986 | Transgenic pigs produced carrying the gene for human growth hormone. |
| 1987 | First field trials in USA of transgenic plants (tomatoes with a gene for insect resistance. |
| | First field trials in USA of genetically-engineered micro-organisms. |
| 1988 | US Patent Office extends patent protection to genetically engineered animals. |
| | First genetically modified micro-organism approved for commercial sale as biocontrol agent of a plant disease (crown-gall of fruit trees in Australia). |

Sources: Adapted from OTA 1984, Wyke 1988.

The prospect of such improvements is in part responsible for the enthusiastic interest that genetic engineering has recently generated among development experts. The present study was initiated in response to this enthusiasm in an effort to determine the scientific, economic, policy, and institutional issues likely to affect the application of biotechnology in the developing world (these issues are defined in Persley, 1989). Several country case studies were also undertaken to assess the current status of biotechnology in various countries (For details on the commissioned papers, see Annex B, and on the country studies, see Annex C). This report deals with the six biotechnology issues of primary concern to the World Bank:

(1) the possible impact of biotechnology on agricultural production, productivity, and international trade;

(2) the institutional and social changes likely to be associated with biotechnology in the developing world;

(3) the changing role of public and private sector investments in agricultural research;

(4) the ecological implications of the environmental release of genetically engineered microorganisms, plants, and animals;

(5) the influence of patent law, plant variety protection, and other means of intellectual property management on national biotechnology activities; and

(6) the possible ways of facilitating greater international assistance to biotechnology in the developing world.

# CHAPTER 2. SOCIOECONOMIC ISSUES

## A. Food Production and Population Trends

The first generation of modern biotechnological techniques has emerged at a time when population growth is slowing down and a surplus of food is building up in the industrial world. Consumption patterns are also changing. Consumers in the industrial countries today spend less than 20 percent of their income on food and are more concerned with choice, taste, health, and presentation than they are with further reductions in the cost of food.

In contrast the developing countries now contain 70 percent of the world's population, a figure that is expected to rise to 90 percent in the next generation. Although world food production has increased at a yearly rate of about 2.7 percent in recent decades, (with food consumption and population growth lagging behind slightly at 2.6 percent and about 2 percent, respectively (IFPRI 1988)), in many regions and countries, particularly in Africa and Asia, food production has not matched population increase and little progress has been made in reducing hunger and poverty. Consequently, there has been a marked increase in the flow of cereals and livestock products from the surpluses in the industrial world to the deficit areas in developing countries. Imports of cereals into developing countries, for example, have increased from 10 million to 70 million tons in the past 20 years (IFPRI, 1988). According to current estimates, food production in the developing world will have to double in the next 25 years just to keep pace with population growth. The great challenge for biotechnology, and indeed for all food production technology, obviously lies in the developing countries, and not in the industrial countries.

Much of the increase in world food production since 1960 has resulted from intensified production of rice, wheat, maize, poultry and dairy products. The basic technologies responsible for this increase are improved plant varieties and animal breeds, greater use of agrichemicals, irrigation expansion, and an increase in multiple cropping. In many countries existing technologies still offer some scope for improving agricultural output further, but there are limits to what can now be achieved. Physiological barriers alone constitute a large constraint to both crop and animal yields. The techniques applied also have their limitations, for instance the production increments achieved with fertilizer and irrigation are tending to decline with each additional unit of expenditure. In addition, environmental considerations are checking rapid expansion of cultivation into range and forest lands, and questions of equity and income distribution are increasingly modifying production strategies. The result is that application of current technologies cannot be expected to double food production in the next 25 years and attention is being directed towards the new technologies as the sources of future production increases.

At present, the time lag between investment in modern biotechnology and the production of economically useful results is about 10 years, which is similar that taken for more conventional agricultural research to result in a new crop variety, animal vaccine, or pharmaceutical. The first significant effects of current investments in biotechnology on production are therefore likely to appear around the year 2000. Thereafter, modern biotechnology is expected to become an increasingly important component of new technologies for crop, forestry, and livestock production.

B. Socioeconomic Impact

According to recent estimates of the potential impact of new technologies on selected temperate crops in the United States, yield increases will not reach half their expected level by the year 2000 if the new technologies are not used (OTA, 1986). The use of biotechnology will contribute to modest but continued increases in productivity of the major crops (1.5-2.0 percent per year); these increases are not likely to be achieved otherwise, since yield plateaus have already been reached for some of the major crops (Barker 1990). Benefits should also show up in the form of improved productivity for tropical commodities and new opportunities for the use of marginal lands that biotechnology will open up and less need for agrichemicals. Failure to apply new technologies for the improvement of food and export commodities in developing countries will put them at a competitive disadvantage in the international marketplace. A disadvantage for developing countries is, however, the possibility that high-value products produced by tissue culture in industrial countries may displace crops presently grown for export in the developing world. To safeguard against the potential negative substitution, international development agencies should make strategic adjustments, and provide flexible loans or grants to assist in crop diversification in individual countries.

As a consequence of the new technologies (Buttel, 1990), the size of farm holdings is also expected to change. New technologies usually consist of packages of several complementary techniques that are difficult and expensive to administer on small farms. The improvement of dairy cattle, for example, is usually introduced through genetic change associated with artificial insemination, production recording progeny testing, and more intensive feeding and husbandry practices. Such changes can put small farmers at a disadvantage. Ultimately, these small-holdings are likely to be displaced by large farms, with centers of production moving to new areas that have developed a greater comparative advantage. Thus, technological change creates a dilemma for smaller farmers and poorer countries. Without a change in technology it will be impossible to meet the demand for basic food commodities, but if technology is introduced, it will be difficult for the small farmer to adjust to the new production circumstances. Even so, as the constraints of energy prices, environmental deterioration, and production plateaus become more pressing, the application of biotechnology will become increasingly important.

To ensure that biotechnology has a positive impact in the developing world, national governments, international development agencies, and private companies currently investing in biotechnology should form alliances that facilitate the process of adaptation. Such groups would play a particularly useful role in countries where public sector research and infrastructure are already well developed (at present there are 10 or so), since these are the countries likely to attract private investment in the future. The challenge for international development agencies lies in the many other countries throughout the world that will need sizable public sector investments to develop their capacity to utilize the products of biotechnology. Such investments should include projects to upgrade the teaching of biological sciences and strengthening more traditional biological research (e.g. plant breeding) as a necessary prerequisite for the use of biotechnology. Greater efforts will also have to be made to encourage policy reforms in world trade, particularly to modify protectionist policies and to reduce the debt burdens of developing nations.

## FINDINGS

Before steps can be taken to initiate major biotechnology programs, a detailed assessment needs to be made of their likely socioeconomic impacts. The principal objectives of such an assessment would be to;

(1) determine the priorities for investments in biotechnology, particularly those that are likely to be of benefit to small farmers and to poorer countries;

(2) identify potential negative effects of the substitution of tropical commodities by novel products in industrial countries and determine the strategic adjustments that could be made to minimize such effects in individual countries; and

(3) identify the social and economic returns to investments in public and private sector biotechnology.

## CHAPTER 3. BIOTECHNOLOGY IN THE INDUSTRIAL WORLD

Modern biotechnology was first used commercially in the United States in the mid-1970s when several companies were established to exploit its application. Almost all the early products were pharmaceuticals and diagnostics developed primarily for markets in industrial countries. In 1987, the total world market for agrichemicals and seeds was about US$113 billion in farm-level sales. Of this amount, 51 percent (US$59 billion) was for fertilizers, 29 percent (US$32 billion) for traded seeds, and 20 percent (US$22 billion) for pesticides. By the year 2000, agricultural biotechnology products are expected to have farm-level sales in the range of US$10 billion to US$100 billion (OECD, 1989). Some industry analysts believe that the lower figure is the more realistic one. Seeds are expected to account for approximately US$7 billion of that amount, agricultural microbiological products US$1 billion, and veterinary products US$2 billion. Novel products are likely to take an increasing share of existing markets. There is likely to be some restructuring rather than a major expansion of the markets for agriculture-related products (Buttel 1990).

In 1985, approximately US$4 billion was spent on research and development activities in modern biotechnology worldwide. The private sector contributed US$2.7 billion (67 percent) of this amount. These levels remained much the same in the OECD countries in 1987 (OTA, 1988a; OECD, 1989). About US$900 million (22 percent) was spent on agricultural-related research and US$3,100 million on other forms of modern biotechnology, mainly in the area of human health care. The total spent on agricultural biotechnology in 1985 was almost US$900 million, of which US$600 million (66 percent) went to seeds and US$300 million (34 percent) to agricultural microbiology. About US$550 million (60 percent) of the total expenditure on agricultural research and development came from the private sector.

The most noticeable change in funding agricultural research in industrial countries in the past decade has been a substantial increase in the role of the private sector, primarily in the funding of research in modern biotechnology. Since private companies are able to appropriate many of the benefits of research investments in this field, it holds more interest for them than the traditional areas of agricultural research, where it is difficult to obtain proprietary rights to the technology generated. The exceptions are agrichemicals and hybrid seeds where, because both of these products can be protected, there has been substantial R&D investment by the private sector.

The types of companies investing in modern biotechnology in agriculture are (1) new biotechnology firms, (2) large agrichemical and seed companies, and (3) other large companies, particularly food companies. Some invest upward of US$5 million per year on R&D in modern biotechnology. In 1986 approximately 134 companies in the United States were involved in agricultural biotechnology, 70 of which were new biotechnology firms (OTA, 1986). At present, the commercial applications of biotechnology are dominated by American and European companies, but Japanese companies have also been showing a growing interest in this area.

Several large agrichemical companies are developing markets for new products through the purchase of seed companies. This allows them to integrate modern biotechnology into conventional plant breeding programs. Some mergers and acquisitions have recently been announced as research and development investments are being rationalized in the light of more realistic market forecasts and better estimates of the likely time-frames for the availability of novel products (Fishlock, 1989).

A new feature in the evolution of biotechnology has been the increasing collaboration between the public and private sector. Private companies often contract specific research projects at public sector institutions and in return obtain some proprietary rights to the technology generated. Continued public sector investments in biotechnology and creative partnerships between public and private sector interests are an essential prerequisite for establishing a competitive national strategy in biotechnology.

A new pattern of agricultural research funding has also emerged from the linkages between biotechnology and academia and commerce. Public research institutions in several industrial countries are now required to raise a substantial part of their research budget from non-government sources via contractual research, licensing agreements, and royalties. The result has been that the traditional systems of open interaction and communication in research are being rapidly altered; and the extent of private investment has become dependant on the potential availability of intellectual property rights for new technologies which has had considerable impact on the type of research being undertaken and the topics chosen for investigation.

Biotechnology research is relatively expensive and specific projects carry an appreciable risk of failure, but, when successful, they are likely to produce large profits. As a result of this risk/reward scenario, research operations need to be flexible enough to capture the profit from product or licence sales and to make greater use of venture capital in financing the research. Public research organizations are also seeking the legal means to enter into joint venture and partnership arrangements with private companies, award research contracts to third partners, tap sources of funding for the production and marketing of novel products, and raise equity financing. Increasing numbers of academics and public sector research scientists have also become entrepreneurs and entered private industry.

## FINDINGS

The influence of the private sector on biotechnology research and development in substantial and experience indicates that public and private sector collaboration will be an effective means of developing and financing biotechnology.

# CHAPTER 4. BIOTECHNOLOGY IN THE DEVELOPING WORLD

## A. Policy Issues

The future management of agricultural research in the developing world will undoubtedly be affected by two recent trends in industrial countries: the increasing participation of the private sector in agricultural research and development, and the narrowing gap between basic science and applied research. The private sector is playing a large role in the biotechnology R&D in the industrial world, especially in partnership with universities. Poorer countries that normally rely on public channels to obtain new technologies free of charge are likely to find the cost of access to private sector sponsored advances in science and technology beyond their means. As a result, the International Agricultural Research Centers (IARCs) may assume greater importance as a means of access to advanced technologies for such countries. The larger and more technologically advanced countries will be able to negotiate their own bilateral arrangements on access to new technologies.

Private sector investment in agricultural R&D has begun to increase in many countries in Asia and Latin America. Such investment is beneficial, particularly for internationally traded commodities, since it can help countries improve their competitive advantage. Policies on patents, tax incentives, contract research, the sharing of resources, and the appropriate division of labor between public and private research entities must be defined in order to encourage this investment (Javier 1990).

In countries considering the possibility of adopting new technologies, it is important that precise national needs be determined from the wide array of products, processes, and areas of research that biotechnology offers. Decisions will be needed on (1) how much to invest in biotechnology relative to other agricultural R&D, (2) on what commodities to invest, and (3) what staffing and infrastructure will be needed to support these investments. The last question is particularly important because many countries lack the basic scientific expertise needed to launch a research program. In these new policy and institutional arrangements and provide for additional financial resources will be needed before basic science laboratories, principally those located in universities, can be mobilized to solve agricultural problems. One of the first steps should be to upgrade the teaching of agricultural science by incorporating modern biotechnology into the teaching curricula. At the higher levels of education, more training in molecular biology, genetics, biochemistry, physiology, genetics, immunology and chemical engineering should be provided (Holloway, 1990).

Introducing a capability in biotechnology R&D is difficult, particularly for countries with a weak base in agricultural science, or those in which universities concentrate on teaching rather than research and there is a shortage of trained personnel and financial support for research. One of the first questions to be resolved is whether to establish a central biotechnology institute or to graft biotechnology onto existing agricultural research programs. Since expertise, facilities, and funds are often limited, many countries will find it cost-effective to plan a central laboratory where an adequate level of resources and effort can be mobilized. At the same time, strong collaborative linkages will have to be established between the agricultural scientists in the central laboratory and those located in other institutions. With a central laboratory servicing the needs of several institutions, it would be unnecessary to duplicate equipment and facilities at every institution with an interest in biotechnology.

Modern biotechnology will not diminish the need for conventional agricultural research. Rather, the demand for new expertise and companion facilities will exert additional pressure on the already limited resources allocated to agricultural research. Close attention will therefore have to be given to the pattern of assistance to agricultural research, with changes introduced to encourage equity funding to facilitate risk sharing, partnership arrangements between private industry and public sector organizations, support for training in biology, effective assessment of research priorities, and local investments in agricultural biotechnology.

Factors that favor the entry of developing countries into biotechnology are their large and growing domestic markets, the opportunities to identify niche markets in which the major transnational companies are neither active nor interested, and the existence within these countries of plant genetic resources for many of the world's major agricultural crops.

B. Selected Country Experiences

The status of biotechnology was assessed in 10 countries of different sizes and at different stages of development: Brunei Darussalem, Indonesia, Malaysia, Philippines, Singapore, Thailand (all of which are ASEAN member countries), Brazil, China, India, and Mexico. Preliminary information was also obtained from Côte d'Ivoire and Zimbabwe. (Further details of the country studies are given in Annex C). The factors used to assess the effectiveness of national biotechnology programs in these countries are summarized in Table 4.1.

Nine countries gave high priority to biotechnology and expressed support for channeling more of the national R&D budget into science and technology. The exception was the relatively oil-rich country of Brunei Darussalem, which has only a small program in biotechnology, as part of an ASEAN/Australia regional project. There was general agreement that biotechnology could help increase agricultural productivity and production. Since most of these countries are dependent on agriculture and are concerned with food security as well as maintaining any existing competitive advantages they have in international markets, many included agricultural biotechnology in their long-term national development plans.

The current agricultural biotechnology programs in these countries focus primarily on plant biotechnology. Some are also involved in industrial applications of fermentation; but animal biotechnology receives the least attention. Micro-propagation and tissue culture are the main activities in plant biotechnology, with emphasis on high-value crops such as ornamentals and cut-flowers. There is also great interest in the production of pathogen-free material, particularly for vegetatively propagated crops, and some interest in germplasm conservation and the production of secondary metabolites.

The industrial applications of agricultural biotechnology concentrate on fermentation processes, primarily in the production of traditional foods, brewing, and the processing of agricultural waste. Waste disposal is an important priority for countries such as Malaysia, which has large amounts of waste biomass from the processing of palm oil. Some of these countries are also interested in producing single-cell protein as a longer-term objective. The main areas of interest in animal biotechnology are embryo transfer, growth hormones, vaccines and diagnostics.

Patent protection appears to be inadequate in all the countries surveyed and is one of the factors discouraging transnational companies from conducting research or marketing biotechnology products in these countries. The local branches of the transnational companies tend to rely on their parent companies to conduct R&D, arguing that opportunities for product commercialization can be explored later, when markets can be more readily assessed.

The lack of private sector involvement in biotechnology has important implications for countries of the developing world. Without it, these countries may lose any comparative advantage that their industry normally has in finishing, commercializing, and distributing agricultural products. Furthermore, without adequate private sector activity and support, it will be difficult to implement a national biotechnology program that benefits fully from the complementary inputs available in both the public and private sector. The lack of industry-university cooperative programs is another serious disadvantage. Experience in the industrial countries indicates that such cooperative programs facilitate the transfer of technology between the public and private sectors.

## FINDINGS

In developing countries an effective national biotechnology program that makes efficient use of domestic and external resources would benefit from the establishment of a well-defined national biotechnology strategy for developing indigenous capability for encouraging the participation of both the public and private sector.

**Table 4.1.** **Assessment of Factors that contribute to the Operation of Effective National Biotechnology Programs in Ten Selected Countries.***

| COUNTRY | % GDP Devoted to Sci & Tech | Public Sector Budget in Biotech (US$ Mil) | Well Defined National | | Domestic Budget Adequate | Human Resources Adequate | Private Sector Activity | Dedicated Biotech Companies | Venture Capital | Adequate Patent Protection | Adequate Environ. Laws | Univ. Ind. Coop. | Inter Tech. Transfer |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Policy | Program | | | | | | | | | |
| BRAZIL | 0.6 | 7 to 15 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 3 | 3 | 2 | 1 |
| BRUNEI | 0.1 | NA | 3 | 3 | 1 | 3 | 3 | 3 | 3 | NA | NA | 3 | 3 |
| CHINA | NA | NA | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| INDIA | 0.9 | 31+ | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 1 | 1 |
| INDONESIA | 0.3 | NA | 1 | 3 | 2 | 3 | 3 | 3 | 3 | NA | NA | NA | 3 |
| MALAYSIA | NA | 0.4 | 1 | 2 | 2 | NA | 3 | 3 | 3 | NA | NA | NA | NA |
| MEXICO | 0.6 | 3 | 1 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 2 |
| PHILIPPINES | 0.2 | 1 | 1 | 2 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| SINGAPORE | 0.9 | 10+ | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 3 | 2 | 1 |
| THAILAND | 0.3 | 7 to 14 | 1 | 1 | 2 | 1 | 3 | 3 | 3 | 3 | 2 | 3 | 2 |

*Legend*

NA - Information not available

1 - Favorable
2 - Acceptable
3 - Low

* Summary prepared by C. James for working papers for Agricultural Biotechnology Seminar, Canberra, May 1989.

## CHAPTER 5. TECHNOLOGY ASSESSMENT

### A. Production Impact

Some of the developments in biotechnology over the past decade have been accompanied by exaggerated claims as to their potential impact on agriculture. More realistic predictions of the effects and time frame of their application are now becoming available. The most reliable estimates come from the United States, where anticipated changes to the year 2000 have been analyzed by the Office of Technology Assessment of the U.S. Congress (OTA, 1986).

According to these estimates, the yields of cotton are expected to increase 0.7 percent per year and wheat and soybeans 1.2 percent. Without the use of new biotechnologies in plants and animals, yield increases are expected to reach only 25-50 percent of these rates. The largest change in the next decade is expected to occur in animal production, mainly as a result of the use of bovine growth hormones (bST) to stimulate milk production in lactating cows. OTA therefore envisaged relatively rapid and widespread adoption of the use of growth hormones and large increases in milk production. The regulatory and trade difficulties now being encountered suggest that this assumption was somewhat over-optimistic.

### B. Crop Production

Several of the modern techniques of biotechnology are applicable to crop production:

(1) Cell and tissue culture is used in the rapid propagation of useful microorganisms and plant species;
(2) New diagnostics based on the use of monoclonal antibodies and nucleic acid probes aid in the diagnosis of plant diseases and the detection of foreign chemicals, such as pesticides, in food;
(3) Genetic engineering may be applied to transfer traits between plant species; and
(4) Genetic mapping techniques are useful tools in plant breeding programs.

Plant biotechnology includes some well-established technologies such as the use of *Rhizobium* bacteria in nitrogen fixation by legume species, and a number of other effective techniques in the biological control of pests, disease diagnosis, and plant breeding. Modern technologies should ideally be grafted onto existing technology systems wherever appropriate and not displace them (Dart, 1990a, 1990b). The main application of new techniques to crop production is expected to lie in the development of new plant varieties with novel characteristics, but this may be hindered in many countries which at present have institutional and infrastructural barriers to plant breeding programs (Duvick, 1989). Greatly strengthened plant breeding programs are a necessary prerequisite for the successful application of plant biotechnology to crop production.

#### Genetic Engineering of Plants

The key components of genetic engineering are: (1) the identification and isolation of the genes suitable for transfer; (2) the design of the delivery systems that will introduce the desired genes into the recipient cells; and (3) the expression of the new genetic information in the recipient cells. At present, techniques are being refined that allow a gene from one species to be transferred and expressed in another species. This process has so far been perfected in about 20 crops (see Table 5.1). The greatest impediment to genetic engineering of plants is the lack of efficient transformation and regeneration systems, especially for monocots, which include the world's main cereal crops. Rapid progress is being made in the genetic manipulation of many species, however, and almost every month another successful plant transformation is reported. Another obstacle to the commercial development of genetic engineering is the paucity of useful genes, which, when transferred with appropriate molecular controls, will confer beneficial traits on the recipient plant.

Some notable successes have been achieved in identifying useful genes, such as those that confer herbicide tolerance, insect resistance, and virus resistance. Model systems have been developed in tobacco and tomato which now need to be adapted to more economically important plants. Crops genetically engineered for insect and/or disease resistance are expected to provide yields similar to those obtained with the use of chemical pesticides. Such crops appear to be particularly well suited to low-input farming in the developing world as the farmer will not have to buy seed every year or need a sophisticated distribution system, additional equipment, or specialized training for their cultivation (Meeusen, 1990).

### Genetic Mapping

A powerful and elegantly simple consequence of recombinant DNA technology is the possibility of constructing a new type of genetic map, known as an restriction fragment length polymorphism (RFLP) map, as an aid to conventional plant breeding programs. RFLP refers to the use of special enzymes known as restriction enzymes to identify specific genetic markers at sites throughout an organism's chromosomes. A detailed map of these locations enables breeders to select precisely for desired traits in otherwise conventional breeding programs. RFLP maps also make it possible to conduct breeding programs for traits controlled by more than one gene. These multigenic traits include many characteristics of value in agriculture, such as yield and drought tolerance.

RFLP maps are becoming an important component of plant breeding programs for many crops (USDA, 1988). The IARCs are already using genetic mapping for some of the major food crops and there is potential for even wider use. In the developing world, genetic mapping could be particularly useful in those crops for which strong conventional breeding programs already exist.

### Agricultural Diagnostics

The new technologies are being applied to the detection of microbes, chemicals (particularly pesticides), and plant products. Improvements in assay technology have led to the development of sensitive, specific, easy-to-use methods for many agricultural purposes (Miller and Williams, 1990). Countries considering the potential application of new agricultural diagnostics should make certain that the technology is well developed and that immediate application is feasible. Once the specific target has been identified the technique should also be applicable to all crops and most pests and diseases. The use (as distinct from preparation) of monoclonal antibodies does not require high technology and their application should be feasible in most countries. It is important to recognize that some new diagnostics may be less expensive to prepare in industrial countries (on a contract basis) rather than in the country of use.

Countries that decide to use modern diagnostics to solve agricultural problems need to consider whether to develop the necessary systems internally, import existing systems from industrial countries, or seek partners in industrial countries to help them develop specific diagnostic systems locally. Much progress could be made by adapting existing systems to meet local needs.

Where a national program is considered necessary, International development agencies could assist individual countries by cooperating with public sector research organizations and private companies in the development of diagnostic kits. Support would be needed for various activities, such as defining end-users and market needs; testing prototypes and final assays to assess local needs and to develop interpretive data; funding for specific projects and/or guaranteeing minimum purchases of kits; training users; and establishing distribution channels.

## FINDINGS

Several new technologies are available for almost immediate application to crop production. Agricultural diagnostics, for example, could be made readily available and used in many countries. Genetic mapping of major tropical crops would be a great boon to conventional plant breeding programs, particularly in the selection for multigenic traits such as drought resistance and salinity tolerance. Other important novel technologies that exist could be used to improve plant virus resistance and to control pests (and thus reduce the use of pesticides).

### C. Livestock Production

Biotechnology is also being applied with some success in the livestock sector. Single-gene products such as the growth hormones of cattle and pigs can be produced in culture in commercial quantities by transferring the cloned gene for the growth hormone to bacteria. Monoclonal antibodies can now be readily produced for use as diagnostic and therapeutic agents, and many new diagnostic reagents are commercially available. Advances are also expected in the sexing, cloning, and transfer of embryos and the selective elimination of male germ cells. The production of new recombinant DNA vaccines has proved to be more difficult than expected because the vaccines produced in bacterial cells are not precisely the same as they would be if produced in animal cells (Cunningham, 1990; Doyle and Spradbrow, 1990). The range of new technologies applicable to livestock production are illustrated in Figure 5.1. Some current problems in livestock production, the possible solutions available from biotechnology, the likely scale of economic impact, and the probable time-frame for application are listed in Table 5.2.

Cattle are the primary target for the application of new technologies. They are the most economically and socially important livestock and their high individual value justifies the cost of new biotechnological inputs. Applications to livestock production should be chosen in accordance with the needs of the small-scale producer, as it will be important to avoid contributing further to the inequities that already exist within and between countries.

## Animal Disease Control

Infectious diseases can be divided into three broad categories: (1) epidemic diseases severely damaging to livestock (e.g. trypanosomiasis); (2) diseases damaging to man and livestock (e.g. rabies); (3) diseases of intensive productive systems. The first two categories are particularly prevalent in the developing world.

Disease control in animals consists of four main activities: diagnosis in the affected livestock, treatment, prevention, and eradication from given populations of livestock, with suitable precautions to prevent it from being reintroduced. Technological advances in these four areas are improving the prospects for controlling livestock diseases in the developing world.

## FINDINGS

The new technologies likely to be applied to livestock production in the developing world in the relatively near future are embryo technology, especially for cattle; new vaccines against infectious diseases; new diagnostics for identifying diseases with greater accuracy; and genetic mapping, as an aid to livestock breeding programs.

Table 5.1 Present Availability of Transformation and Regeneration Systems For crops

| Cereals | Fibre Crops | Food Legumes and oilseeds | Horticultural crops | Pastures | Trees |
|---|---|---|---|---|---|
| Maize | Cotton | Flax | Carrot | Lucerne | Poplar |
| Rye | | Rapeseed | Cauliflower | Stylo-santhes | Walnut |
| | | Soybean | Celery | | |
| | | | Cucumber | | |
| | | | Potato | | |
| | | | Tobacco | | |
| | | | Tomato | | |

Figure 5.1 Biotechnology in Livestock Production

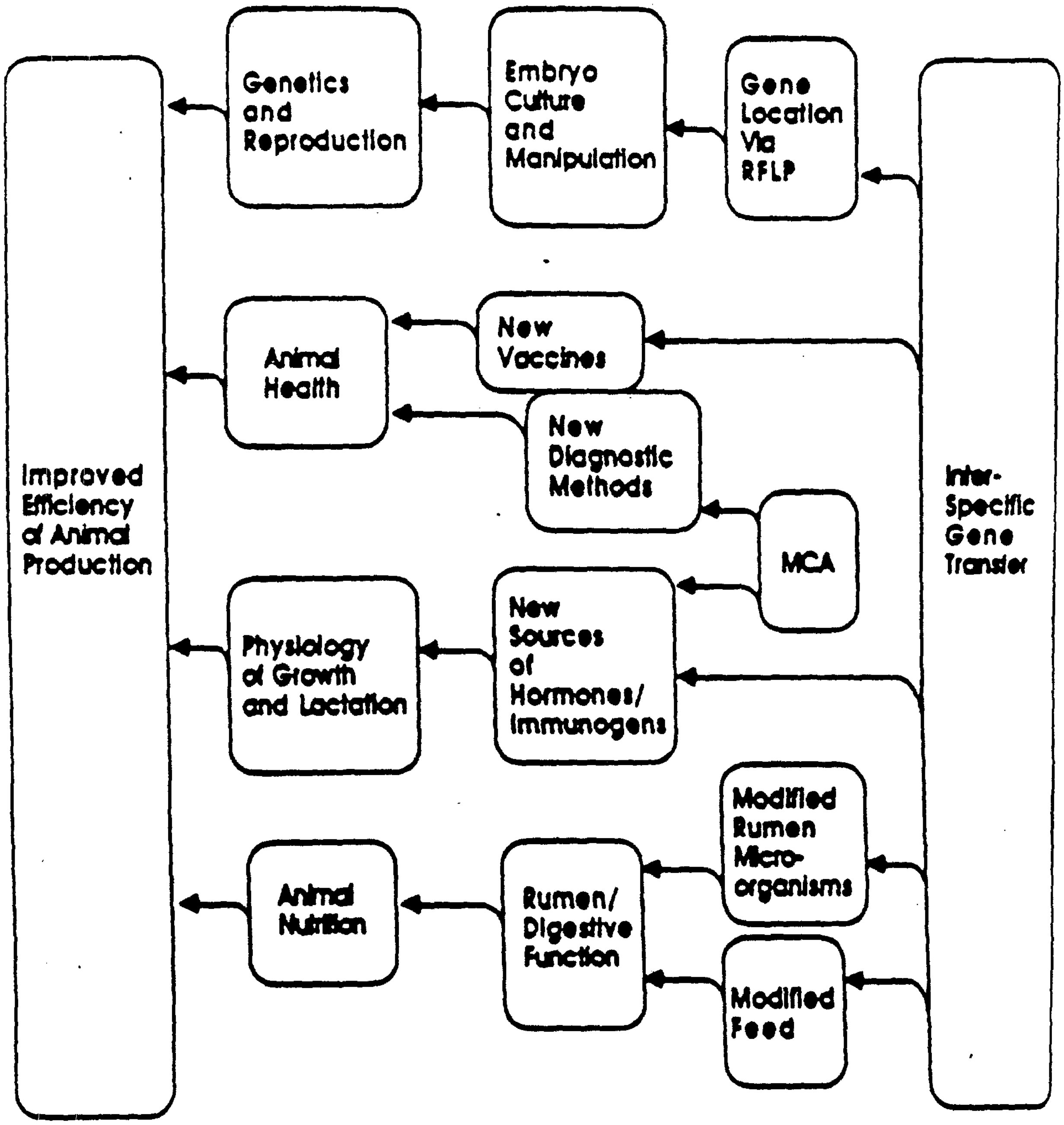


**Table 5.2** **Possible Applications of Biotechnology to the Solution of Livestock Production Problems in the Third World**

| Problem | Possible Biotechnology Solution | Scale of Economic Impact | Probable Time to Commercial Use |
|---|---|---|---|
| Animal, poultry, fish, diseases | new vaccines | large | short |
| | new diagnostics | moderate | short |
| Poor quality of forages | microbial treatment of forages | moderate | medium |
| | modification of rumen microflora | moderate/ large | long |
| | genetic improvement of forages and their symbionts | moderate | medium |
| Difficulty of implementing selection programs | selection in nucleus herds, using ET, sexing | large | medium |
| | use of RFLP markers to assist selection | moderate | medium |
| Difficulty of maintaining dairy cattle performance after F1 cross | use of IVF, ET and sexing | large | long |
| Cost and environmental challenge to imported cattle | use of ET to import embyros | small | short |
| Need for increased efficiency in intensive systems | use of rBST and rPST in dairy and pig production | large | short |

Time Frame: Short: now or before 5 years; Medium: 5 to 10 years
Long: over 10 years

Abbreviations: ET: embyro transfer; RFLP: restriction fragment length polymorphism, or direct DNA typing of individuals; IVF: *in vitro* fertilisation; rBST: recombinant bovine or porcine somatotropin (growth hormones produced using recombinant DNA technology)

Sources: Cunningham (1990); Doyle and Spradbrow (1990)

# CHAPTER 6. COMMODITY ANALYSIS

The first step in assessing the usefulness of a new agricultural technology is to identify the problems that have been intractable by conventional means but may be solved by the application of new technologies. The focus must be on the problems to be solved and not on the new technology itself. Furthermore, in the analysis of what needs to be done, it is important to combine the expertise of those who understand the commodity and its needs with the skills of modern biologists who see new ways to approach old problems. Genetic engineers are the new partners of agricultural scientists, not their replacements.

The productivity constraints in several important commodities in the developing world have been examined with a view to identifying the likely new technologies that may be available for their resolution. These crops (banana/plantain, cassava, cocoa, coffee, coconut, oil palm, potato, rapeseed, rice, and wheat) and the available technologies are listed in Table 6.1. The current constraints to production for each and the potential biotechnology solutions are given in Table 6.2. Substantial progress may be expected in the short term (0-5 years) for potato, rapeseed, and rice; in the medium term (5-10 years) for banana/plantain, cassava, and coffee; and only in the long-term (10+ years) for cocoa, coconut, oil palm, and wheat.

## FINDINGS

(1) The early applications of modern biotechnology are likely to be on crops of primary interest to the industrial world.

(2) Support should also be provided for applications of biotechnology to "orphan commodities," namely, those that are important in the developing world but that have been overlooked by modern biotechnology because they are of little importance to the industrial world.

(3) An "orphan commodities program" could be established under international auspices to sponsor collaborative research among public and private sector organizations in order to ensure that orphan commodities would also benefit from the application of new technologies. It could be modeled on an existing orphan drug program that sponsors the preparation of pharmaceuticals for the developing world.

Table 6.1 Availability of New Technologies for Selected Crops

| Crop[1] | New diagnostics[2] | Rapid propagation systems[3] | Transformation systems[4] | Regeneration systems[5] | Time Frame[6] |
|---|---|---|---|---|---|
| Banana/ Plantain | + | + | - | + | Medium |
| Cassava | + | + | - | - | Medium |
| Cocoa | + | - | - | - | Long |
| Coconut | + | - | - | - | Long |
| Coffee | + | + | - | + | Medium |
| Oilpalm | + | + | - | - | Long |
| Potato | + | + | + | + | Short |
| Rapeseed | + | + | + | + | Short |
| Rice | + | + | + | + | Short |
| Wheat | + | + | - | - | Long |

Notes

1. Crop: Illustrative examples of crops important as food and/or export crops in the developing world.

2. Availability of new diagnostics for pests or diseases based on the use of monoclonal antibodies or nucleic acid probes.

3. Availability of rapid propagation systems to allow the multiplication of new varieties.

4. Availability of transformation systems to enable new genetic information to be inserted into single plant cells.

5. Availability of regeneration systems to enable single cells to be regenerated into whole plants.

6. Likely time frame for commercial applications of new technology: Short-term, 0-5 years; medium-term, 5-10 years; long-term, >10 years.

Table 6.2 Commodity Constraints and Potential Biotechnology Solutions

| Commodity | Constraints | Potential bio-technology solutions | Time-frame | Sources |
|---|---|---|---|---|
| Banana/ Plantain | Black Sigatoka disease ) Bunchy top virus ) Fusarium wilt ) | new diagnostics host plant resistance | short long | Dale (1990) |
| Cassava | high cyanide | new varieties | long | Bertram (1990) |
| | cassava mosaic virus | host plant resistance | medium | |
| Coffee | coffee rust | host plant resistance | medium | Sondahl (1990) |
| | quality characteristics | new varieties | long | |
| Cocoa | lack of vegetative propagation | novel tissue culture techniques | long | Sondahl (1990) |
| Coconut | lack of vegetative propagation | novel tissue culture techniques | medium | Jones (1990b) |
| | virus/viroid diseases | new diagnostics | short | |
| | lethal yellowing disease | genetic mapping | long | |
| Oilpalm | clonal propagation flowering abnormalities | novel tissue culture methods | medium | Jones (1990b) |
| | drought susceptibility | genetic mapping | long | |
| | pests and diseases | genetic engineering | long | |
| | oil quality | genetic engineering | long | |
| Potato | high temperature susceptibility | genetic mapping | short | Dodds & Tejeda (1990) |
| | lack of disease-free planting material post harvest quality | new tissue culture techniques and new diagnostics | short | |
| Rapeseed | oil-quality | genetic mapping | medium | Scowcroft (1990) |
| Rice | virus diseases | genetic engineering | medium | Toennison & Herdt (1990) |
| Wheat | fungal diseases ) virus diseases (barley) yellow dwarf) ) | genetic engineering | long | Larkin (1990) |

Notes: Short term, now or <5 years; medium term, 5-10 years, long term, 10+ years.

The future of biotechnology in agriculture will be affected by country policies toward the management of intellectual property. In the United States, patent protection has been granted under existing legislation to biotechnological processes (in the 1970's) and to novel microorganisms (1980), plants (1985), and animals (1989) produced using recombinant DNA technology (OTA 1989). Several other OECD countries also offer some patent protection to biotechnological products and processes. Such protection is rare in other countries and this situation has discouraged both local private companies and transnational corporations from investing in biotechnology.

The private sector is highly motivated to invest in biotechnology in industrial countries because of the protection available on the use of any novel products and processes that result from research in this area. A number of methods are available for protecting innovations: (1) seed and breed certificates, (2) plant patent and variety protection, (3) invention patents, (4) petty patents, (5) inventors' certificates, (6) industrial design patents, (7) copyrights, and (8) trade secrecy.

Efforts to develop an international system of intellectual property rights (IPR) are moving slowly as a result of disagreements between the three groups with a direct interest in the development of biotechnology: the technology sellers, the technology buyers with a strong indigenous adaptive capacity, and the technology buyers with little research capacity. Strong patent laws are important to technology sellers. For countries with no significant patent sales in other countries, the present patent conventions are not relevant. Many countries do not regard the IPR requested by the industrial countries as a "natural right" but as a negotiating issue through which they may obtain other concessions in return for opening their technology markets. IPR are being debated in the current round of GATT negotiations and in the World Intellectual Property Organization in Geneva.

The issues surrounding patent protection in biotechnology are described in detail in Evenson and Putman (1990) and Barton (1989). Those of major concern include (1) the limitations to be placed on the franchise of foreign firms that would supply the technology, (2) the protection to be provided to the progeny of plants and animals covered by an IPR agreement, (3) the breadth of distribution of germplasm originating from the IARCs, and (4) the role of "petty patents" in stimulating local adaptive research.

There are advantages in providing IPR in biotechnology. They encourage the development of local research capacity and private sector investments, particularly by transnational companies interested in developing specific products for local markets. IPR may also be used in bargaining for improved access to overseas markets for a nation's export commodities. The main disadvantage is that IPR give proprietary protection to living organisms that some consider to be part of the common heritage of mankind. Each country needs to weigh the benefits and cost of such rights and frame its policies accordingly.

Licensing arrangements and other contractual agreements are among the solutions that have already been suggested as a means of providing countries with greater access to biotechnological products while also protecting the legitimate interests of their inventors. International development agencies and the IARCs could facilitate such access by negotiating (possibly on behalf of a consortium of countries) for the licencing of new technologies to apply to commodities important in the developing world.

The IARCs could also patent their own inventions and then license (freely, if appropriate) these inventions for use by national agricultural research systems (NARS) and other collaborators. Such action would not only protect the centers from any attempt by third parties to patent their inventions, but also enable them to earn royalties on their inventions, which could be used to fund further research.

## FINDINGS

Information on the management of intellectual property should be made available to individual countries in order to help them weigh the costs and benefits of such action in relation to biotechnology. Where the benefits outweigh the costs, suitable patent systems could be designed on a country-by-country basis.

The need for regulations to govern the release of genetically engineered organisms into the environment is another important policy issue connected with the use of biotechnology. An efficient regulatory process that emphasizes safety of human health and the environment is in itself advantageous to the biotechnology industry since it helps to allay public concern and provides a safety net which protects both the manufacturer and the potential consumers. By mid-1990, there have been 187 deliberate releases of genetically modified plants and microorganisms in 17 countries, under existing guidelines or legislation. A genetically modified bacterium is on sale as a biocontrol agent in Australia (Kerr 1989).

Early research on genetic engineering was tightly controlled through the guidelines that grew out of the Asilomar Conference held in the United States in 1975. As experience with the new technologies has accumulated, more liberal regulatory policies have become acceptable in several countries. Four definitive statements on regulating environmental applications of genetically engineered organisms have been published in the United States to date, two by the U.S. National Academy of Sciences (NAS, 1987, 1989), one by the Office of Technology Assessment of the U.S. Congress (OTA, 1988b), and one by the Ecological Society of America (Tiedje et al., 1989). They all make similar recommendations concerning regulatory action. All are cautiously optimistic that the benefits of the new technologies, will outweigh the risks and that mechanisms exist to allow regulatory authorities to assess the levels of risk and to enforce appropriate safeguards.

Statements on environmental release have also been issued by the OECD (1986) which provides internationally endorsed recommendations concerning safety considerations when releasing genetically engineered organisms and by the Australian Recombinant DNA Monitoring Committee (Millis, 1989). The U.K. Royal Commission on Environmental Pollution recently published a report on the release of genetically engineered organisms into the environment (Anon., 1989). The Australian guidelines for risk assessment are further developed in Tiedje et al.,(1989).

Many OECD countries have already enacted regulations governing the release of new biological products from any source. Most of these pertain to the release of agrichemicals, biological control agents, and new plant varieties and therefore are relevant to the products of modern biotechnology as well as the more conventionally produced products. They provide the necessary protection to ensure that the products of biotechnology will not be sold commercially without prior approval.

In countries without such laws or guidelines, the situation is less satisfactory. Therefore the United Nations organizations UNEP and UNIDO are reviewing the needs of their member countries to ensure that safe and efficient regulatory processes are available to all countries.

Statutory regulations are not enthusiastically received by either government authorities or biotechnologists when they are excessively rigid, expensive, and time-consuming. Such regulations may be self-defeating in that they encourage unauthorized experimentation. Some countries prefer to issue guidelines through a technical committee rather than official legislation in order to permit flexibility and rapid change as the field of biotechnology expands (Millis, 1990).

Once appropriate guidelines have been established, the next step is to form a hierarchy of biosafety committees, at the institutional and national level. This should be responsible for (1) certifying the security of the facilities used for genetic engineering work according to the category of risk; (2) approving proposals at the institutional level for work in the lowest category of risk and forwarding to the national committee for review any proposals in which the institutional committee is uncertain of the risk, or the genetic construct is one of perceptibly high risk; (3) ensuring that advice from the national biosafety committee is followed, and that the appropriate training of workers is included, (4) regularly inspecting the containment facilities; and (5) providing the national biosafety committee with regular listings of all current work involving genetic manipulation.

All countries need to establish national review bodies and institutional biosafety committees and develop guidelines to monitor and regulate their applications of biotechnology. The IARCs should have their own institutional biosafety committees and should make sure that they function in accordance with the approval mechanisms of the host country. In addition, all review bodies should keep abreast of current developments in risk assessment and the results of related ecological studies so that they can be incorporated into their own biosafety procedures.

## FINDINGS

(1) Individual countries should be encouraged to establish active and well-informed national review bodies and institutional biosafety committees to monitor and regulate the release of genetically engineered organisms into the environment. The national body and its guidelines should be framed so as to complement and support existing regulatory agencies.

(2) The IARCs should be encouraged to establish international biosafety committees wherever these do not exist and should ensure that these function in accordance with the approval mechanisms of the host country.

(3) National review bodies in individual countries and the IARCs should be kept informed of the assessments and current policies of functioning national biosafety review committees in other countries, particularly in connection with environmental risk assessment procedures.

(4) Bio-safety reviews following national guidelines should be conducted prior to release of genetically engineered organisms in any projects sponsored by international development agencies.

# CHAPTER 9. INTERNATIONAL AGRICULTURAL RESEARCH CENTERS

Most of the IARCs concerned with crop or livestock improvement are already involved in biotechnology research, at either modest or substantial levels. Their current programs are described in detail by Plucknett, Cohen, and Horne (1990). Some potential applications of biotechnology in the crop improvement programs at these centers are listed in Table 9.1.

The IARCs can play an important role in tailoring the modern techniques to the needs of agriculture in the developing world. This will require, however, research strategies to be modified to favor biotechnological research. Their clients are likely to be the many smaller and poorer countries (70 or more), rather than the more technologically advanced countries (10 or less). The latter are developing their own capacity for biotechnology and will probably require little assistance from the international centers, other than some occasional advice.

Any IARC expecting to undertake biotechnology projects in earnest must have the following capabilities:

(1) a critical mass of in-house scientific expertise to monitor, choose, and utilize new products and processes, and to adapt them to the limiting factors in developing world agriculture;

(2) the skills needed to acquire new technologies from the public or private sector in industrial countries, under suitable licencing and/or royalty arrangements if necessary;

(3) the scientific and managerial skills needed to develop well-chosen and effective collaborative research programs with the best public and private sector laboratories in industrial and newly industrialized countries (this will require legal and financial skills not commonly available at the centers, but which could be provided on a CGIAR-system-wide basis);

(4) the research capacity to integrate new technologies into existing R&D programs (particularly plant breeding);

(5) support for the necessary complementary research in physiology, pathology, entomology, cytogenetics, etc. to provide the scientific basis for future genetic improvements; and

(6) adequate biosafety guidelines that are compatible with the regulatory environment of the host country.

Some IARCs have already begun moving their research programs in the direction of biotechnology, while others are making plans to do so. If the IARCs are to remain at the forefront of tropical agricultural science, they will need to develop substantive biotechnology programs within the next decade. This will necessitate a reallocation of some existing resources and personnel and additional targeted funds.

In the early stages of the programs, these funds could be used to introduce the new biotechnologies (such as RFLP mapping) to plant breeding programs, to integrated pest management with a view to reducing pesticide usage, to build up plant resistance to the economically threatening virus diseases, and to develop new diagnostics for plant and animal diseases.

To enable the IARCs to adapt the tools of biotechnology to the demands of developing world agriculture new methods for acquiring technologies are needed. They should be able to negotiate with the private sector on their own behalf, and, if required, on behalf of consortia of developing countries. It may also be necessary to establish a licensing system granting these centers the use of a particular technology in a manner analogous to the purchase of proprietary computer software. The relative strengths of the IARCs and the private sector must be understood and defined before any productive relationships can be established between them (USAID, 1989; James and Persley, 1990).

To acquire new technologies, especially in an area that is changing as rapidly as biotechnology, the IARCs must be able to observe, choose, and utilize ideas that might prove useful in crop or livestock improvement. Most centers will therefore need scientists on staff who are abreast of scientific advances and capable of judging whether they will be useful in agricultural research. To do this well, the scientists must be able to bridge the gap between basic biological sciences and agricultural sciences. Some bridging courses in modern biotechnology may be useful for senior center scientists and research managers to help them become familiar with the new technologies available and their potential contribution to the center's current R&D programs. The international Laboratory for Research on Animal Diseases has used this approach with some success to increase its expertise in the modern advances.

IARCs located in countries remote from institutions where modern biology is evolving may wish to consider other staffing arrangements to gain access to new scientific developments. For example, a center staff member could be located in an advanced institute in an industrial country, and monitor new developments and establish collaborative linkages with the R&D programs of the IARC. Posting staff in such laboratories may prove more cost-effective than trying to keep a biotechnologist at the center's headquarters up-to-date in a rapidly changing technology.

Centers must also develop expertise for the acquisition of new technologies and in the ability to decide on the type of technology needed and discriminate between the various options available, the expected costs of each, and the time it will take before they can be applied in practical agriculture. Once this decision-making process has taken place and a technology selected, the center must determine how, and from where, it can be acquired (Plucknett et al., 1990). The search for new technologies should not be restricted to the public domain. Recent advances in the private sector, coupled with its expressed interest in working with the IARCs suggest that private collaborations should be considered as another option. The efforts of the IARCs and NARS to acquire, develop, and apply the new technologies would benefit greatly from expanded linkages among the centers, national institutions, and biotechnology practitioners elsewhere, both public and private.

The relationship between the new biotechnologies and the objectives of the "Green Revolution" are outlined in Table 9.2. In the light of the new capabilities, the IARCs should focus their attention on (1) distributing improved germplasm through the private sector as well as through national research systems; (2) moving their research upstream toward more strategic programs; (3) relying on patents or other property rights for processes and products, and obtaining protection for proprietary lines prior to use; (4) integrating molecular and cellular biology with conventional breeding to achieve new advances; (5) complying with national and international regulatory standards, especially those involving genetic engineering; (6) maintaining and enhancing strategic alliances for collaborative research required to augment center-oriented research; (7) undertaking more direct commercial involvement as national programs and IARCs collaborate with the private sector; and (8) employing new germplasm to achieve genetic gains (Plucknett et al., 1990).

## FINDINGS

The IARCS should be provided with additional support to allow them to expand the following types of activities and strengthen their programs in biotechnology:

(1) Scientific Expertise at the IARCs: facilitate scientific interchanges, including university and industrial postdoctoral research; the development of interdisciplinary teams that would work on new technologies and apply them to specific agricultural constraints; and the out-posting of center staff to advanced laboratories, where they could monitor new developments and identify potentially useful technologies.

(2) Technology acquisition: facilitate the acquisition of new technologies, including technologies from the private sector, through purchase, licensing, or other agreements on royalties; collaborative research designed to benefit interests of both parties; market analysis; technology appraisal.

(3) Verification: facilitate the testing of model systems in contained experiments before they are used on a wide scale.

(4) Application development: encourage national programs and commercial concerns to apply biotechnology to agricultural development.

(5) Outreach: provide opportunities for training, extension, and adaptive research in NARS in client countries.

(6) Policy and management issues: collaborate with NARS in defining national policies for biotechnology and in preparing national biotechnology programs, appropriate to the size and scientific infrastructure within a particular country.

Table 9.1 Potential Applications of Biotechnology in Crop Improvement Programs

| **Components of Conventional Germplasm-based Technologies** | **Conventional Time Span** | **Potential Biotechnology Contribution** |
|---|---|---|
| Germplasm | | |
| A. Acquisition/Exchange | 1 year | In vitro culture, disease indexing and eradication, micropropagation. |
| B. Conservation | Ongoing | In vitro conservation, gene libraries |
| C. Evaluation | 2 seasons | Molecular diagnostics, RFLPs. |
| D. Germplasm Enhancement | 3-5 seasons | Embyro rescue, molecular diagnostics, selection in tissue culture, somaclonal variation, gene transfer. |
| E. Wide Hybridization | 2 years | Embryo rescue, somaclonal variation, anther culture, protoplast fusion |
| Breeding | | |
| A. Selection of Parental Germplasm<br>1. Elite lines<br>2. Adapted populations<br>3. Exotic materials | | Molecular diagnostics, tissue culture derived lines, gene transfer. |
| B. Initial Development Cross (F1) | 1 year | |
| C. Production and Selection of Segregating Lines (F2-F3) | 2 seasons | Somoclonal variation, anther culture, molecular diagnostics, RFLP mapping. |
| D. Controlled Inbreeding (F4-F7) | 3-4 seasons | |
| E. Bulk Increase of Finished Lines | 2 seasons | Pathogen elimination, micropropagation. |
| Testing | | |
| A. Observational Trials and/or Preliminary Testing | 2 seasons | |
| B. International Trials | 2 seasons | |
| C. Advanced Testing in National Coordinated Trials | 2 seasons | Molecular diagnostics |
| D. Farmer's Field Trials | 2 seasons | |
| Distribution | | |
| A. Bulk Increase | 1-2 seasons | Micropropagation |
| B. Certification | 1 season | Disease indexing and eradication |
| C. Quarantine | 1 season | Disease indexing, molecular diagnostics, micropropagation |

Source: Plucknett, Cohen, and Horne (1990)

Table 9.2 Attributes of the 'Green Revolution' and Their Relation to Modern Biotechnology

| Green Revolution Attribute | Potential Impact of New Advances |
| --- | --- |
| Improved germplasm distributed through national agricultural research systems. | Distributing improved germplasm through national research systems as well as through private sector. |
| CGIAR centers primarily conducting downstream or applied and adaptive research. | Encouraging CGIAR centers to move research upstream towards more strategic programs. |
| Patents and plant variety protection used minimally. | Research institutes using patents for product protection or proprietary lines prior to use. |
| Considered conventional research technologies sufficient to sustain agronomic progress. | Integrating molecular and cellular biology with conventional breeding for agronomic advances. |
| Sought minimal involvement with regulatory concerns regarding biological manipulation and transport, except for quarantine. | Complying with national and international regulatory standards, especially those involving genetic engineering. |
| Maintained strong reliance on research based at the IARC for breeding advancements. | Maintaining and enhancing collaborative research required to augment center-based research. |
| Required little commercial involvement for technology dissemination. | Considering more direct commercial involvement. |
| Depended upon germplasm to achieve genetic gains. | Using new sources of germplasm to increase productivity through genetic manipulations. |

Source: Plucknett, Cohen, and Horne 1990

# CHAPTER 10. WORLD BANK INVESTMENTS

## A. Current Support for Agricultural Research

As noted throughout this report, biotechnology is offering new answers to old problems--how to increase crop and livestock productivity and protect the environment by reducing the use of agrichemicals. Up to now, the new technologies have been applied mainly in medicine, industry, and agriculture in industrial countries, with significant investments coming from transnational companies. As a strong supporter of agricultural research and rural development, the World Bank is in a position to ensure that the needs of the developing world are not ignored in the current research and development efforts in biotechnology.

The Bank Group provides support for agricultural research through loans, credits and grants. Between 1981 and 1987, the Bank supported 21 national agricultural research projects, with total loans and credits of US$575 million. These projects were located in Bangladesh, Brazil, Cameroon, China, Colombia, Ethiopia, India, Malawi, Malaysia, Pakistan, Papua New Guinea, Peru, Philippines, Rwanda, Senegal, Sri Lanka, Sudan, Thailand, Zambia, Zimbabwe, and The Yemen Arab Republic. During the same period, it provided US$2.1 billion in support of research components within 209 rural development projects. Additional support for agricultural research was provided through 12 educational projects and 16 policy-based loans (Pritchard, 1990).

The Bank grants support research conducted by the IARCs and sponsored by the CGIAR and other non-associated centers. In 1988, these grant funds amounted to US$32 million.

The Bank is currently providing substantial support for research in the field of agricultural biotechnology, although the precise amount is difficult to estimate since biotechnology is generally a small component of Bank projects and is not described in detail in project documents. Between 1982 and 1988, the Bank supported 10 agricultural projects with specific biotechnology components in Brazil, Cyprus, Hungary, Indonesia, Madagascar, Malaysia, Rwanda, Senegal, Sri Lanka, and Sudan. The biotechnology components of these projects received at least US$93 million in support. Further funding has been provided through the education and science and technology components of projects in Brazil, Indonesia, and Portugal.

The Bank's current projects include support for biotechnology infrastructure, laboratory facilities and equipment, and training. Most projects recognize the need for a strong association between the public and private sector. Some support is also being provided for research and development programs focusing on the tissue culture of various crop and forest species and on bioprocessing. Most of this current lending is flowing to the more economically advanced countries, primarily to pharmaceuticals and human health, rather than agricultural biotechnology (Pritchard, 1990).

## FINDINGS

Various instruments within the Bank are available for providing additional support for the application of biotechnology to agricultural problems:

(1) Loans and credits for national agricultural research projects in individual countries are increasingly including biotechnology components, consisting of technical assistance and research partnerships with scientists in advanced laboratories. Such approaches help developing countries acquire and adapt the new technologies to the needs of agriculture in the developing world.

(2) Joint Ventures with The International Finance Corporation (IFC) could help local private sector companies participate in the commercial development of biotechnology.

(3) Grant funds to the IARCs permit an expansion in the capacity of the centers in modern biotechnology and and if targeted could help them undertake collaborative research with advanced laboratories.

## CHAPTER 11. OPTIONS FOR INTERNATIONAL DEVELOPMENT AGENCIES

One of the more pressing challenges facing countries of the developing world is to double their food production in the next 25 years. More and better grain varieties, fertilizer, and irrigation will continue to provide the basis of the required production programs, but energy prices, environmental deterioration, and production plateaus now require new solutions, which are increasingly being sought in biotechnology. The difficulty is that many NARS have limited resources and will be unable to expand their efforts unless new policy and institutional arrangements are made to strengthen collaborative research and training linkages with established biotechnology laboratories elsewhere. The private sector must also be encouraged to step up its participation in agricultural research.

An obstacle to the acquisition of new technologies will be IPR, which are assuming great importance, particularly in the industrial countries. NARS must therefore develop the skills to be able to identify research developments relevant to local problems and negotiate the acquisition of this technology. Early efforts at acquisition are likely to focus on innovations already tried and proved elsewhere, such as micro-propagation and pathogen elimination in cell and tissue culture, improved diagnostic techniques, and vaccine production for localized diseases.

Wherever biotechnology research is carried out (whether in a central biotechnology institute or in some part of an existing agricultural research system) the critical ingredient will be interdisciplinary collaboration among molecular biologists, pathologists, agronomists, and breeders. New initiatives rather than new institutions will be the key to success and these must build on traditional strengths in agricultural research, not displace them.

Critical questions facing countries seeking to develop a capability in biotechnology are how to integrate biotechnology into their existing agricultural research programs, plan the training and retraining of staff, gain access to and adapt technology developed elsewhere, arrange and finance collaborative agreements with other biotechnology enterprises, protect the rights to unique germplasm, and safeguard against environmental and social repercussions.

The solution of these questions requires a strong foundation in the basic biological sciences. A foundation that is available in relatively few developing countries. Much of the skill in applying biotechnology to agricultural production problems resides in the private sector of the industrial countries, many of which also have a strong and publicly financed research system that is reinforced by the demands of an active agricultural industry. To strengthen their capability in biotechnology, the developing countries must seek collaborative research and implementation agreements between the public and private sectors across country boundaries. International development agencies can facilitate the transfer of information and techniques and thus help the developing countries capture the benefits of the new technologies.

The policy designed to increase the flow of these benefits from countries with a strong research capacity to those with weak systems should include measures to ensure that the benefits will be available to all developing countries. It should also encourage research and development activities that will strengthen the productive capacity of small farmers and should protect the environment by ensuring that the new technologies will be applied judiciously.

Before the international development agencies can respond operationally to these objectives, they must themselves become fully apprised of the technology available, identify ways to bring that information to bear on specific problems, and acquire the skills needed to use it. In addition, they will need to develop the skills for negotiating the licensing of technology and genetic constructs whose use is governed by IPR. Measures should also be taken to protect society from any unwise release of new biological materials.

These tasks go well beyond the technical responsibilities that international development agencies normally accept in preparing projects. The skills required to accomplish them have not yet been fully developed in the nonprofit foundations, IARCs, or private consultant groups. This is a large obstacle preventing international development agencies from offering greater support to agricultural biotechnology. Consequently, it is critical for these agencies to strengthen their in-house capacity in biotechnology and to seek assistance from external experts in project preparation.

## FINDINGS

International development agencies interested in facilitating the application of biotechnology to agriculture in the developing world have several courses of action open to them:

Option 1. Public Sector Support They can provide support for biotechnology in association with support allocated for other agricultural research at public sector institutions.

Option 2. Public/Private Sector Support They can provide support for biotechnology in public sector institutions in developing countries together with support for collaborative research with advanced laboratories elsewhere. Private companies may choose to participate in such collaborative activities either through a research contract or through participation in a specific project, which may have commercial potential beyond the project itself. This option would require prior agreement on the management of IPR.

Option 3. Commercial Joint Ventures Development agencies could facilitate the establishment of commercially viable joint ventures between public and private sector agencies. These ventures could focus on developing new products and processes, and the business systems needed to deliver novel products to the end users in the developing world. Agencies would also need to devise innovative funding mechanisms that would allow them to work more closely with the private sector in agricultural R&D in the developing world.

## CHAPTER 12. CONCLUSIONS

The new techniques of modern biotechnology offer the developing countries renewed hope of resolving many of their serious agricultural problems. Unfortunately, many countries do not yet have the resources or the skills to take advantage of these new technologies. Thus, the onus is on the international development agencies to devise innovative funding mechanisms and new programs that incorporate biotechnology. Such programs should be designed in collaboration with individual countries in the developing world and with the public and private institutions currently forging ahead with the development of modern technology. The dialogue should concentrate on identifying potentially useful technologies and adapting them to the needs of agriculture in individual countries. The international development agencies must make an all-out effort to devise new ways of doing business.

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# ANNEX A
## GLOSSARY OF TERMS

Amino acid: Any one of a group of 20 chemicals that are linked together in various combinations to form proteins. Each protein is made up of a specific sequence of these chemicals. This unique sequence is coded for by a gene.

Anti-codon: A particular combination of three bases in transfer-RNA that is complementary to a specific three-base codon in messenger RNA. Alignment of codons and anti-codons is the basis for organizing amino acids into a specific sequence in a protein chain.

Bacterium: Any of a group of one-celled micro-organisms having (pl. bacteria):round, rod-like, spiral, or filamentous bodies that are enclosed by a cell wall or membrane and lack fully differentiated nuclei.

Base: The units of nucleic acids. In DNA, the four bases are adenine (A), guanine (G), cytosine (C) and thymine (T). In RNA, the base uracil (U) replaces thymine. Bases are sometimes called nucleotides.

Base pairing rule: Two bases, one in each strand of a double-stranded DNA molecule, are attracted to one another on the basis of their chemical structure, so that G (guanine) always pairs with C (cytosine), and A (adenine) pairs with T (thymine) in DNA or U (uracil), in RNA. Thus by knowing the sequence of bases in one strand of DNA, it is possible to predict the sequence in the opposite, complementary strand.

Biotechnology: Any technique that uses living organism or substances from those organisms to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses. These techniques include the use of new technologies such as recombinant DNA, cell fusion, and other new bioprocesses.

Cell: The smallest component of life. A membrane-bound protoplasmic body capable of carrying on all essential life processes. A single cell unit is a complex collection of molecules with many different activities.

DNA (deoxyribonucleic acid): The molecule that is the repository of genetic information in all organisms (with the exception of a few viruses). The information coded by DNA determine the structure and function of an organism.

Chromosome(s): The physical structure(s) within a cell's nucleus, composed of a DNA-protein complex, and containing the hereditary material i.e genes; in bacteria the DNA molecule is a single closed circle (without protein).

DNA sequencing: Determination of the order of bases in a DNA molecule.

Enzyme: A protein that accelerates a specific chemical reaction, without itself being destroyed.

Gene: The fundamental physical and functional unit of heredity, the portion of a DNA molecule that is made up of an ordered sequence of nucleotide base pairs that produce a specific product or have an assigned function.

Genetic code: The code that translates information contained in messenger RNA into amino acids. Different triplets of bases (called codons) code for each of 20 different amino acids.

Genetic engineering: Technologies (including recombinant DNA technologies) used by scientists to isolate genes from an organism, manipulate them in the laboratory, and insert them into another organism.

Genotype: The genetic constitution of an organism as distinguished from its physical appearance (phenotype).

Germplasm: The total genetic variability, represented by germ cells or seeds, available to a particular population of organisms.

Hybrid: An offspring of a cross between two genetically unlike individual plants or animals.

Hybridoma: A new cell resulting from the fusion of a particular type of immortal tumor cell line, a myeloma, with an antibody-producing B lymphocyte. Cultures of such cells are capable of continuous growth and specific (i.e., monoclonal) antibody production.

Intellectual property: That area of the law involving patents, copyrights, trademarks, trade secrets, and plant variety protection.

Ligase: An enzyme that joins the ends of DNA molecules together. These enzymes are essential tools in genetic engineering.

Recombinant DNA: Hybrid DNA sequences assembled in vitro from different sources; or hybrid DNA sequences from the same source assembled in vitro in a novel configuration.

Monoclonal antibodies: Identical antibodies that recognize a single, specific antigen and are produced by a clone of specialized cells.

Restriction enzymes: Certain bacterial enzymes that recognize specific short sequences of DNA and cut the DNA where these sites occur.

RNA (Ribonucleic acid): Nucleic acid complementary to DNA. The three kinds of RNA important in the genetic processes in cells are messenger RNA (mRNA), ribosomal RNA (rRNA) and transfer RNA (tRNA).

Species: Reproductive communities and populations that are distinguished by their collective manifestation of ranges of variation with respect to many different characteristics and qualities.

Tissue culture: The propagation of tissue removed from organisms in a laboratory environment that has strict sterility, temperature, and nutrient requirements.

Transcription: The process of converting information in DNA into information contained in messenger RNA.

Transfer RNA (tRNA): RNA that is used to position amino acids in the correct order during protein construction.

Transformation: Introduction and assimilation of DNA from one organism to another via uptake of naked DNA.

Transgenic animals or plants: Animals or plants whose hereditary DNA has been augmented by the addition of DNA from a source other than parental germplasm, in a laboratory using recombinant DNA techniques.

Translation: The process of converting the information in messenger RNA into protein.

Vector: A carrier or transmission agent. In the context of recombinant DNA technology, a vector is the DNA molecule used to introduce foreign DNA into host cells. Recombinant DNA vectors include plasmids, bacteriophages, and other forms of DNA.

Sources: OTA 1988, 1989.

## ANNEX B
## LIST OF COMMISSIONED PAPERS

### Section One: Background Papers

| | |
|---|---|
| Biotechnology for Bankers | G.J. Persley/ W.J. Peacock |
| Classifying Biotechnologies | K.A. Jones |

### Section Two: Plant Production and Agricultural Microbiology

| | |
|---|---|
| Plant Production: Introduction | P. Dart |
| Agricultural Microbiology: Introduction | P. Dart |
| Plant Breeding | D.N. Duvick |
| Agricultural Diagnostics | S.A. Miller/ R.J. Williams |
| Insect and Disease Resistance | R.L. Meeusen |
| Biocontrol of Insects and Weeds | M.J. Whitten/ J.G. Oakshott |
| Beneficial Microorganisms | J.E.Beringer |

### Section Three: Plant Production and Agricultural Biotechnology

| | |
|---|---|
| Annual Vegetable Oil Crops | W.R. Scowcroft |
| Perennial Vegetable Oil Crops | L.H. Jones |
| Cassava | R.B. Bertram |
| Banana and Plantain | J.L. Dale |
| Wheat | P.J. Larkin |
| Potato | J.H. Dodds/ M. Tejeda |
| Coffee and Cocoa | M.R. Söndahl |
| Forestry | S.L. Krugman |

Section Four: Livestock and Fisheries

| | |
|---|---|
| Animal Health | J.J. Doyle/<br>P.B. Spradbrow |
| Animal Production | E.P. Cunningham |
| Aquaculture | D.R. Fielder/<br>P.B. Spadbrow/<br>P.J.Dart |

Section Five: Bioprocessing

| | |
|---|---|
| Microbial Bioprocessing | L.V. Giddings |

Section Six: Policy Issues

| | |
|---|---|
| Socioeconomic Impact | R. Barker |
| Sociological Impact | F.H. Buttel |
| Regulating Release of Organisms | N.F. Millis |
| Intellectual Property | R.E. Evenson/<br>J.Putman |
| Role of the Private Sector | C. James/<br>G.J.Persley |
| Infrastructural Requirements | J. Raff |
| Commercial Prospects | W.H. Bollinger |
| Role of the International Agricultural Research Centers | D. Plucknett/<br>J.I. Cohen/<br>M.Horne |
| Issues for National Agricultural Research Systems | E. Javier |
| Educational Needs | B. Holloway |
| Role of the World Bank | P. Brumby/<br>A. Pritchard/<br>G.J. Persley |

The addresses of the authors of the commissioned papers are given in the list of contributors in Annex D.

The commissioned papers from the study are being published in a separate volume entitled, "Agricultural Biotechnology-Opportunities for International Development (Ed. G.J. Persley), CAB International, Wallingford, U.K. (480p).

The policy issues are elaborated further in a volume, entitled, "Beyond Mendel's Garden : Biotechnology in the Service of World Agriculture" (G.J. Persley). CAB International, Wallingford, U.K. (155p).

## ANNEX C
## LIST OF COUNTRY STUDY REPORTS

ASEAN Member Countries (Brunei Darussalam, Indonesia, Malaysia, Philippines, Singapore and Thailand)

Gibbons, G. and Youngyuth, Y. (1989). Biotechnology Country Case Study Reports on the ASEAN Nations.

BRAZIL

Barton, J. (1989) and Sondahl, M. (1989). Biotechnology in Brazil

CHINA

Xu Shi Hong and Jia Shi-Rong. Agricultural Biotechnology in China.

INDIA

Jones, K.A. (1989). Agricultural Biotechnology in India. A Country Study

MEXICO

James, C., Blanco, A., Galindo, J. and Herra, L. (1989). Status of Agricultural Biotechnology in Mexico.

Copies of the individual country case study reports are available from the International Service for National Agricultural Research (ISNAR), P.O. Box 93375, 2509AJ, The Hague, Netherlands.

A working paper prepared for the Agricultural Biotechnology Seminar, Canberra, May 1989 by C. James, containing summaries of the country reports is also available from ISNAR.

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