# BIOTECHNOLOGY IN DEVELOPING COUNTRIES

## Research Advances and Applications

Edited by

William Edwardson
Michael Graham

For additional copies, or for further information about this document, please contact the authors at the following address:

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE
ENVIRONMENT AND NATURAL RESOURCES DIVISION
P. O. BOX 8500
OTTAWA, ONTARIO
CANADA, K1G 3H9
TEL: (613) 236-6163
FAX: (613) 567-7749

February, 1994

# Acknowledgments

Special thanks are given to the authors of the original papers both for their contributions and for their active participation in the conference. Their papers are reproduced in unedited form in this book, and their ideas have been used in the synthesis and the discussion summary.

Thanks are also extended to Chusa Gines for her assistance with the coordination of the presentations and the organization of the seminar.

# Contents

# Foreword

Biotechnology is being applied in ways that will affect agriculture, health, the environment, and many other aspects of science and industry in the decades to come. Most current applications are centred in the developed countries and, as a result, priorities for research and development are, in general, established by these nations.

As the number of biotechnology-derived products increases, they can be expected both to co-exist with conventional products and to replace them. The development of new products, and the competition and new opportunities they will create, has serious implications for developing countries.

Biotechnology processes depend on sources of raw materials that can be processed into new products with a much higher value. These biological resources are found naturally in many developing countries, but are at risk due to ever-increasing populations, agricultural expansion, logging, and resettlement programs. Without a sustained conservation effort, many species of plants and animals will disappear. Continued loss of biodiversity would be a serious blow to biotechnology and this situation begs for cooperation between countries that are rich in biological resources but poor in technological resources, and countries that are rich in technological resources but poor in biological resources.

Developing countries must prepare now to take advantage of the coming opportunities that biotechnology will provide. For this reason, the International Development Research Centre invited leading developing country scientists to prepare papers expressing their views on the opportunities, progress, and problems of biotechnology in their regions of the developing world. Christopher Chetsanga from Africa, José Luis Solleiro from Latin America, and Setijati D. Sastrapradja and G.P. Talwar from Asia presented their views first at a seminar in Ottawa and then at a larger forum, the Bio-Recognition — Industrial Biotechnology Conference in Montreal (June 1992). Gaston Grenier, from Africa, acted as moderator and provided a summary of the discussions. This publication presents their papers along with a synthesis of the major elements of their presentations. We are indebted to them for their efforts.

They make a strong case for attention to alternative applications of biotechnology for the specific needs and constraints of developing countries — related more to agricultural and food, tropical diseases, and public health than to the high-value pharmaceutical product orientation of biotechnology in developed countries.

IDRC in its new strategy will be addressing key issues presented in Agenda 21, the action document resulting from the Rio Conference on Environment and Development, which took place at the same time as the Montreal meeting. Agenda 21 allocates an entire chapter to highlighting the importance of environmentally sound application of biotechnology for development. IDRC therefore will draw on the recommendations and ideas presented at the Montreal meeting to identify and implement its program of support for biotechnology over the next few years.

Given the importance of the issues and the complexity of the problems confronting the development of biotechnology in the developing countries, greater understanding among all nations, both developing and developed, is required. It is our hope that this publication will help governments, development agencies, and the private sector to adjust their policies and programs so that developing country populations, particularly the poor, will gain access to the benefits that will flow from new applications of biotechnology.

**William Edwardson**
*Senior Program Officer*
*Environment and Natural Resources*
*International Development Research Centre*

# Major Issues in Biotechnology for Developing Countries: A Synthesis of Presentations

*Michael Graham*

## What is Biotechnology?

Biotechnology is a field of study that seeks to generate new products and processes using the concepts and methods of modern biology. It blends the principles and practices of biochemistry, genetics, and microbiology. Recent breakthroughs in molecular biology have transformed biotechnology into a science that has produced refinements to areas such as protein chemistry, nucleic acid biochemistry, fermentation, and immunology. These advances are having an impact in agriculture, aquaculture, animal productivity, and health care.

Although the roots of this technology are ancient and have been employed in fermentation processes for hundreds of years, "biotechnology" as a new science was rejuvenated by developments in molecular biology, genetic engineering, and cell chemistry. Over the past 15 years, biotechnology has provided opportunities to create and support many new industries in the countries of the North, but these bioindustries are just now beginning the profitable phase of their life cycle.

For developing countries, the promise of biotechnology is particularly strong. Problems associated with population pressures, food insufficiency, and nutritional deficiencies, environmental degradation, and the need to create employment could well be partially solved by new technological innovations presented by advances in biotechnology. However, to face these challenges, governments in developing countries must develop appropriate plans and policies, and invest in capacity building. Otherwise, much of this potential may be lost. It is crucial that countries be able to define their own priorities and devise ways in which these emerging technologies will enhance resource exploitation.

Biotechnology promises many positive benefits. At the same time, it poses some potential negative consequences. Among the projected positive outcomes of advances in biotechnology are:

(1) Increases in farming productivity and in food production by the use of plant biotechnology to complement conventional technologies.

(2) Improved nutrition brought about by increases in farming and agro-industrial production, and the use of fermentation techniques in food processing.

(3) Better integration of food production with the production and consumption of bioenergy, especially in small rural communities.

(4) Improved production of livestock, and better health of domestic animals.

(5) Improved diagnosis and prevention of human diseases, as well as improvements in public health.

(6) Increases in income and employment opportunities.

(7) Improve pollution control.

Some of the potential negative consequences of advances in biotechnology include:

(1) Shifts in trade patterns between developing and developed countries due to changes in productivity brought about by improvements in farming and agro-industrial activities and the marketing of new biological products that will have a tendency to displace raw materials and products from developing countries (i.e., substitution of agricultural products).

(2) An expansion in the area devoted to cash crops in developing countries at the expense of traditional food crops.

(3) The strengthening of large farming operations and the subsequent displacement of small farmers and its effect on the economic sector.

(4) Possible reduction in genetic diversity as a result of the broad distribution of new crops varieties, and the potential for increased soil erosion.

(5) Increased privatization of the results of research, which could reduce access to them by developing countries and force them to pay fees for the use of seeds and plant varieties developed by the industrialized countries.

(6) Greater possibilities of risk to health and therefore a need for emphasis on biosafety.

All these factors will have far-reaching consequences. New biotechnologies are likely to be adopted by developing countries in the sectors of their economies with the greatest potential for growth. As a result, there will be a trend toward centralization of ownership of farmland. Under these circumstances, small producers and hired labourers are likely to suffer and the trend of migration from rural to urban areas can be expected to accelerate.

Developing countries also fear that they may not be able to obtain appropriate technologies from the industrialized countries. Given the barriers erected against the transfer of biotechnology, Third World countries will have to concern themselves with maximizing their natural, scientific, and technological resources to define problems and seek solutions that will benefit broad sectors of their populations.

Faced with this prospect, the only way to confront these risks while taking advantage of existing opportunities, will be for developing countries to gain greater control over biotechnology. To a great extent, success in using biotechnology will depend on the level of scientific and technological knowledge that these countries are able to develop in this emerging field.

## Why the Enthusiasm?

Every year the World Resource Institute, together with United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP), produces a publication on world resources. The most recent figures make it clear that the world's population continues to grow at an alarming rate. Two-thirds of this growth is in the developing world. In India alone, the population increases by 69,000 each day. Increases of this magnitude place great pressures on governments to find innovative ways to provide food, health, shelter, and jobs for their citizens.

Food production in developing countries has increased remarkably during the past two decades. This success was achieved, in large part, through the application of fertilizers and pesticides as well as the planting of high-yielding crop varieties. Moreover, arable land was available to expand the area under cultivation. Food production today faces ever-increasing challenges created by increasing populations. Under present agricultural practices, there are signs that production of high-yielding varieties is beginning to level off. Arable land can no longer be found easily in most developing countries and this is forcing farmers onto marginal land. Meanwhile, excessive applications of fertilizers and pesticides degrade the environment. These challenges require new approaches.

For many developing countries, agriculture produces food as well as earns foreign exchange. For centuries, many developing countries have exported agricultural commodities. In these countries, large areas are occupied by plantations of oil palm, tea, coffee, cacao, sugar cane, and cotton. Production technologies for those commodities are well developed. However, to continue to compete in the world market, technologies for processing need to be refined because competition from new products produced through biotechnology continues to grow. For example, the market for natural vanilla has been reduced by the in vitro production of vanillin and the use of sugarcane has been reduced because of the extraction of fructose from maize. The next crops likely to be affected are cacao and tomato.

The need to increase food production and to meet the challenges of new products has made many developing countries eager to grasp the potential of biotechnology to increase the production and value of their commodities.

Many Third World countries are rich in biological resources, including plants with medicinal properties. These species have been used for centuries to maintain health and cure illness. Pharmaceutical industries process the products from these species into high-value substances. Many other tropical species are also used in the cosmetics industry. Both of these industries are likely to grow in the coming years under the control of multinational corporations.

Many crop and animal species in the tropics have received little attention from biologists because they often have limited distributions and are valuable only to local communities. But, the characteristics that have adapted these traditional varieties to local conditions are very important inputs when scientists seek to develop new varieties for specific purposes. Biotechnology can help identify these characteristics and shorten the time needed to incorporate the desired characteristics into new varieties. However, developing countries will need to establish their own programs to improve these varieties as they may not be of interest to countries and companies in the North due to small markets. For example, the Institut International de Recherche Scientifique pour le Developpement en Afrique (IIRSDA) has focused work on yams, which are locally important, but have no industrial agricultural applications in developed countries. This situation is in contrast to the work that has been done in Africa on cassava, which has contributed in large part to dairy production in Holland.

The myriad of plants, animals, and microbes that live in tropical forests are an important component of the world's biological resources. They are an important resource for developing and developed countries alike. These forest resources have declined at an accelerated rate throughout the 1980s due to agricultural expansion, wood extraction, and resettlement programs. This reduction in forest areas has an effect on endemic species of both plants and animals. Reforestation programs are thus becoming a priority in many nations. This, in turn, requires the production of massive amounts of planting material. Traditional means of propagation are insufficient to meet the demand. Biotechnology offers the potential of rapid selection and multiplication of the desired species. For some trees, such as wild fruit trees, overexploitation can cause their total elimination if rapid propagation systems and new management systems are not developed.

# What has been Achieved?

Some Third World governments saw the potential for the application of biotechnology in industry, health, and agriculture and made research and development in biotechnology a priority. Countries with advanced infrastructure and sufficient resources are now ready to absorb new techniques developed in this field. Countries with limited resources are struggling to keep pace with developments.

The most widely used technique in agricultural biotechnology in these countries is tissue culture. Commercially, it is used in the production of potatoes and flowers, palm trees, bananas and plantains, and coffee. On a laboratory scale, success has been achieved in the rapid multiplication of forest tree species, such as teak, acacia, and casuarina. More sophisticated techniques, such as cell and protoplast fusion, gene cloning, gene transfer, DNA-finger printing, and cell immobilization are at various stages of application.

In the field of medical biotechnology, Third World governments are developing diagnostic kits and vaccines for major tropical diseases, such as hepatitis B, dengue fever, malaria, and amoebiasis. Vector control programs, such as the onchocerciasis control program in West Africa, use thousands of tonnes of *Bacillus thuringiensis* per year (which is produced in developed countries).

In many cases it is the more technologically advanced countries, such as the United States and Japan, that are playing a leading role. However, other countries have also made significant advances. Developing countries are far behind; however, a Chinese institute has offered monoclonal antibodies against human T lymphocytes. In India, tissue culture techniques have been used for mass propagation of bamboo saplings, strains of algae are being developed and tested as sources of nitrogen in traditional planting systems, genetically improved fish are being used in aquaculture projects, embryo transfer technology is being used to improve cattle herds, new methods are being developed for fertility control in humans, vaccines are under development to treat leprosy, and a diagnostic kit is being developed for *Salmonella*. In Zimbabwe, efforts have been directed mostly at improvements in agriculture. For example, micropropagation techniques are being used to produce disease-free seedlings, efforts are being made to isolate and characterize milk-fermenting bacteria to improve traditional milk fermentation, investigations are continuing to develop a fast method to detect strains of bacteria that cause abortions in cattle, and work is being done on the genome of the hepatitis B virus that is responsible for causing primary liver cancer in people. Also in Africa, 22 nitrogen-fixing trees have been identified and used in Kenya, cryopreservation of coconut tree embryos and rapid micropropagation of improved palm trees are in use in Côté d'Ivoire, *Rhizobium* inoculant is being produced in a dozen centres in Africa, and many national institutes have designed and used systems for in vitro preservation of many vegetatively reproduced domestic plants. In Latin America, fermented beverages and milk products are produced using inputs from biotechnology as are antibiotics, amino acids, organic acids, and biofertilizers. Efforts to engineer new characteristics into local plant varieties are also being conducted in some countries of the region. However, it is important to underline the fact that most of these applications do not employ the advanced techniques of new biotechnology, rather they build on improvements in traditional biotechnology. Most developing countries have little experience or access to the new knowledge.

Although many research activities are being conducted, a much smaller number of applications have been developed through the use of biotechnologies in the developing world. Efforts are needed to understand how various policies and practices influence the development and commercialization of these products.

## The Role of the Public and Private Sectors

In developing countries, the public sector plays a dominant role in the launching of biotechnology activities. Recently, new institutions have been established for biotechnology in many countries. In Asia, a Department of Biotechnology in the Ministry of Science and Technology was set up in 1986 by the Government of India; Indonesia has established a Centre for Research in Biotechnology under the Indonesian Institute of Sciences; the Federal Ministry of Education of Pakistan has organized a National Centre of Excellence in Molecular Biology, and in Thailand a National Centre for Genetic Engineering and Biotechnology (NCGEB) was organized in 1983. In Mexico, biotechnology has been in the operating budget of the National Council of Science and Technology since 1984. Efforts in Zimbabwe saw a Master's Degree program initiated in biotechnology in 1991 and a National Biotechnology Research Institute is under construction.

The driving force behind the commercialization of biotechnology is financial profit. In some developed countries, a part of biotechnology research starts in both the private and public sectors. However, it soon transfers to the private sector once there are signs of market opportunities. Today, two-thirds of biotechnology spending in developed countries comes from the private sector. Transnational corporations are by far the leading spenders.

But in most developing countries, the private sector is weak. There are only a few industries capable of acquiring and assimilating new biotechnologies and then producing and commercializing new products in the global market. Indigenous industries generally prefer to buy technologies from the world market. Industries affiliated with transnational corporations draw most of the research and development needed for their manufacturing activities from their headquarters. This situation creates a climate in which transnational corporations have no urgent need for new technologies to be derived from research and development work supported by the public sector. Unless this condition is altered by developing better relationships between the public and private sectors, the results of biotechnology research produced by the private sector may not be made available to the public sector corporations. There are also a number of structural problems that must be resolved as well. For example, the over-valued currency in a country like Côté d'Ivoire makes it more attractive to import the raw material at a disguised subsidized price than to prepare this raw material locally for further processing and marketing on the local market.

The privatization of biotechnology products and processes has fuelled the international debate on intellectual property rights. A few developing countries (i.e., Korea, Mexico, Venezuela, Colombia, and Chile) have intellectual property rights on crop varieties and plant products and many others are analyzing modifications to their patent laws. In principle, these biological resources are a common heritage and should be freely accessible. Biotechnology is, on the other hand, a technology whose results are being patented and made available only for a price.

## Control of Innovations

Obtaining patent rights for biotechnology inventions has become a fundamental objective of companies seeking to commercialize biotechnology. The main beneficiaries of the patenting process are the large multinational corporations. These companies seek to patent their products or processes in a given country, with the primary objective of restricting the wider use of the technology. They would prefer to export it and eliminate possible competition.

As the number of potential applications for biotechnology has risen, a race has developed for control of the resulting innovations and the markets they will dominate. This control is increasingly being exercised by large international corporations.
European, American, and Japanese companies currently compete in the open market. Success in this market is difficult because several entry barriers must be overcome. These barriers can be particularly daunting for developing nations.

The first difficulty is that research in biotechnology requires a solid interdisciplinary scientific team with expertise in such areas as molecular genetics, immunology, protein chemistry, biophysics, industrial microbiology, computer sciences, and engineering.

The resources necessary to undertake biotechnology research and development can also be a serious obstacle. Resource requirements go beyond the exclusive scope of the research activity. In fact, the greater the scale of the biotechnology operations to be undertaken, the greater the relevance of the availability of such material resources as equipment, process control instruments, and standardized raw materials. For this reason, new suppliers of the special inputs, such as super-producing fermentation strains, required by biotechnology companies continue to spring up.

Even when developing countries develop technological capacity, this does not guarantee successful commercial and economic biotechnology operations. Efforts to distribute and market biotechnology products may encounter barriers that are far more complicated than those posed by the technical problems. Many start-up companies therefore have no alternative than to grant the marketing rights for their products to other well-established companies.

These factors limit access by developing countries to biotechnologies, as well as their capacity to adapt processes developed elsewhere.

To benefit from the potential applications in the biotechnology field, developing countries need to confront the problem of technological information dissemination and define policies and practices that will make it possible for them to use biotechnology to find solutions to their specific needs.

This means that efforts must be made to develop local capacities to select, acquire, develop, and promote biotechnology products and processes in sectors where the country has clear comparative advantages. Countries must therefore be selective and make honest analyses of their strengths and weaknesses to realistically identify their comparative advantages.

## Establishing a Biotechnology Policy

As developing nations establish national biotechnology strategies it is essential that they develop appropriate legal and regulatory frameworks as part of their biotechnology policies.

Complying with regulatory requirements in biotechnology is a critical factor affecting the time and cost necessary to market a product. All applications of biotechnology should include an assessment of the possible dangers to ensure the health and safety of workers, consumers, and the environment.

Industrialized countries currently have regulatory procedures for biotechnology products. Consequently, approvals are time-consuming and costly. If a developing country does not have such regulatory procedures, they may become the experimental ground for the release of genetically engineered organisms by foreign industries. In cases of collaboration between developed and developing country laboratories, developing countries should insist that any field tests conducted in their test stations follow the guidelines established in the developed country for the handling of the organism.

The Commission on Plant Genetic Resources of the Food and Agriculture Organization (FAO), in its Fourth Session (1991), devoted considerable discussion to the development of legal and regulatory procedures. The handling and release of genetically modified organisms and intellectual property rights over plant genetic resources has become a focus of attention.

The regulatory system must also build confidence, make economic sense, and be compatible with international regulations. The system must permit long-term development planning and marketing of new products, while being flexible enough to adapt itself to the characteristics of each new development.

It is also important that efforts be made to ensure that poor farmers on small plots of land in the developing world are able to benefit from biotechnology inputs. It is these farmers who have developed, in many cases, the traditional varieties that are the raw materials for biotechnology. After several years of discussion, the concept of Farmer's Rights is now recognized by FAO. These rights provide for farmers all over the world to be compensated if their materials are developed into high-value products. However, it will take time for this concept to be worked out and put into routine practice.

Developing countries face problems when trying to establish biotechnology policies. To start with it can be difficult to define and classify biotechnology. Often there is also a lack of a reliable information on biotechnology in these countries, and a lack of knowledge about biotechnology and its importance among various executive levels of government due to poor links with the country's scientists. Biotechnology as a science can be limited by: (1) the application of inadequate methodologies; (2) a lack of mechanisms to use the results of research; and (3) limited numbers of scientists.

However, in view of the positive and negative effects that biotechnology can have, countries must make efforts to develop and consolidate the development of biotechnology. This will mean that countries need to increase investments in research and development to increase their scientific capacity and to improve their abilities to adopt and assimilate biotechnologies developed abroad. They must also develop a monitoring system to keep pace with global developments and to be aware of potential suppliers of technology. In those regions where countries are too small or too poor to develop their own biotechnology sector alternative regional mechanisms may be needed.

When a country is developing a comprehensive policy for biotechnology, it is important that this be done in such a way that other policy areas, such as science, technology, industry, finance, export, and regional development become complementary. Certain prerequisites are necessary before a biotechnology policy can be established. These prerequisites include:

(1) A strong scientific establishment must be in place that is able to develop technology of its own or to negotiate or adapt technologies originating in other countries.

(2) A solid technological and scientific infrastructure is indispensable and will require a significant increase in research and development expenditures by both the government and the private sector.

(3) Because the most important production factor is qualified human resources, a definite training policy in both the basic sciences and engineering is crucial.

(4) Human resources and capital are scarce; therefore, priorities must be established for biotechnology developments, otherwise resources will be spread too thinly.

(5) Biotechnology policies must be linked with macroeconomic policies, and with other policies that impact on other sectors of the economy.

(6) When policies are being formulated, they should be developed in a sequence that: (a) establishes long-term strategic objectives and defines priorities; (b) defines opportunities and requirements for different regions and/or sectors; (c) selects or designs policies for each priority in the biotechnology field; and (d) defines roles, action plans, and agreements among different participants.

As these conditions are met, defining a biotechnology development plan should become a national priority. The options and priorities identified in the national plan must take into account the country's strengths and weaknesses, as well as the opportunities and challenges that are presented. The following issues are likely to be part of a comprehensive national plan.

## Financing and Evaluation

Funding for biotechnology should cover the development of infrastructure, basic research, contribution of venture capital (for technological development and investment), scholarship programs, and exchanges with other countries. Funds should be allocated in accordance with established priorities.

However, although many countries have made biotechnology one of their top priorities in their research and development agenda, there are large differences in the commitment of resources.

Research in biotechnology can cover a wide range of topics and be undertaken at different levels of sophistication. In many developing countries these activities have led to the mastering of new techniques in biotechnology. Quite often, however, this capability is scattered throughout different research units.

It is important that as programs in biotechnology are developed the potential benefits are evaluated. Biotechnology has been shown to have applications in industry, medical care, and agriculture. But in developing countries, human and financial resources are limited in all three areas. Because of this limitation, priorities must be set if biotechnology is to contribute to development. This means that within research programs, economic returns and social implications should be addressed at the same time as technical matters are evaluated. This is an area that requires research to develop new tools to do this adequately, in particular when the contemplated products are to be directed at the poorest people.

## Training of Human Resources

Biological resources are the raw materials used by biotechnology processes. Of these, it is the plant genetic resources that are most widely used in biotechnology. Alone, these resources mean little to a country. They require human skills and the appropriate technologies to achieve their potential. Included in the required technology is a delivery system.

There is a widespread agreement that modern biotechnology requires the development and application of biochemistry, microbiology, molecular biology, and genetics. As a result, any biotechnology program will have to assign high priority to strengthening human resources training in these areas. An associated difficulty is "brain drain", which is particularly important in biotechnology. For this reason, training should take place, when possible, at centres of excellence in the developing country of origin or another developing country.

Expert human resources in general are rather limited in the developing world. Trained personnel often have many duties (such as administration) and are left with no time to do research. However, it is research that enhances technology acquisition, adaptation, and development.

## Information

Access to technical information enhances access to new technologies and can strengthen a country's negotiating position with outside agencies. A network of libraries and technical documentation centres that incorporates the latest advances for retrieval, storage, and dissemination of information should be provided. As well, scientists need to attend regional meetings to share ideas.

## Links with Developed Countries

Although there are many signs that new technologies are more closely guarded than ever, the door is not yet closed. Developing countries should use all means of international cooperation at their disposal. Sponsoring students to attend first-class universities and research centres on scholarships is an important means of accessing new knowledge. However, other kinds of collaboration such as technology transfer, investments, and alliances are also needed.

## Enterprise Development

An efficient mechanism for biotechnology dissemination is the creation of so-called knowledge enterprises. In key areas, national or regional companies can be promoted and protected until they become established in the market.

## Fiscal Incentives

It is important that the private sector make a contribution to national research and development. For this reason, governments should provide incentives for research and development activities, for the creation of infrastructure and information, and for the training and development of human resources.

## Purchasing Policies of the Public Sector

The public sector is the largest buyer in any country. Therefore, it can promote national technologies by purchasing goods produced by means of new biotechnologies.

## Safety

The application of biotechnology is not free from danger. Training courses should be organized on safety measures and supported with manuals and other training materials.

## Links Between Research and the Productive Sector

Research and development activities are carried out in universities, research institutes, and to some extent in industries. In modern biotechnology, interactions between research centres and the productive sector are critical. In sub-Saharan Africa, the critical mass can only be achieved through subregional research centres. It is necessary that means be developed to encourage research centres, industry, and government institutions to work together. Several countries have a centralized policy, which helps to coordinate efforts. In other countries, each research unit has its own interests and these are not necessarily related to solving domestic problems. Such fragmentation prevents the pooling of scarce resources.

### Industrial Property

Modern industrial property laws should be developed because they help promote biotechnology inventiveness. However, it is also important to place special care on the information aspects of patents so that inventors can reveal their invention in exchange for legal protection. For this measure to fulfil its objective of promoting the flow of knowledge, the patent office must communicate information on patents through an active dissemination system. However, many countries do not have the resources to implement such regulations. For example, in 1989, Kenya adopted a patent law similar to British law. However, because of lack of funds, there is no registering system and no employee to implement the system.

## Development Assistance

When building a national capability for biotechnology, developing countries often receive external donor support. Several programs have been established to assist Third World countries to develop this national capability. When these programs are implemented it is important that they have a clear focus so their effectiveness can be measured. As well, it important to heed several lessons have been learned from the past: (1) biotechnology research requires a long-term commitment by donors; (2) an enlightened "smart" human resources management process is needed; (3) at least a minimal amount of infrastructure is essential; (4) a thorough assessment of the needs of the target group is needed; and (5) it must be flexible to allow for a multidisciplinary approach.

### The United Nations System

Several UN agencies assist their members to develop human resources for biotechnology and other closely related subjects. For example: United Nations Industrial Development Organization; Food and Agriculture Organization; United Nations Environment Programme; and United Nations Education, Science, and Cultural Organization.

### The Consultative Group on International Agricultural Research

Because research is required to sustain what was achieved in grain production during the "green" revolution, this consultative group (CGIAR) was established jointly by FAO, UNDP, and World Bank. Within this system, there are now 17 research institutes in which biotechnology is applied.

Through the crop improvement programs of these international agricultural research centres, research programs are tackled with biotechnology and other appropriate techniques. Such cooperation develops new capabilities and skills in the partner countries while developing new varieties and agricultural techniques.

### Bilateral Assistance

New techniques in biotechnology are derived mainly from cellular and molecular biology. Because molecular biologists are scarce in most developing countries, it is difficult to tap into existing applications, let alone develop new applications for local purposes. Technical assistance programs cover many areas including biotechnology. These government to government arrangements cater to the individual needs of each country. Both degree and non-degree training enhances human resources development. Often coupled with these programs is the inclusion of the equipment necessary to establish laboratories.

### Other Sources

International foundations and other donor organizations such as IDRC support the development of biotechnology for developing countries. For example, a world-wide network on rice biotechnology is sponsored by the Rockefeller Foundation. Transnational corporations also have strong programs in biotechnology. Developing countries can take advantage of these opportunities. It is clear that cooperation with the private sector is desirable, however, caution should be exercised to ensure that concerns about biosafety and the control of new technologies are taken into account.

## Potential for Biotechnology

Biotechnology has the potential to modify and improve the economic and social conditions of the populations living in the developing world. In the long run, it will create a new worldwide "revolution" in agriculture. Biotechnology may well generate a greater impact in this sector than the so-called "agro-chemical" or "green" revolution of the 1960s and 1970s. It could allow developing countries to improve their self-reliance in both the quality and quantity of the food they produce, to increase their competitiveness on the international commodity markets, and to produce products to satisfy specific needs.

Biotechnology also has the potential to produce improvements in the health and energy sectors of many developing countries and to help resolve difficult problems such as population growth. However, to produce these benefits, it is essential that developing countries themselves promote research, development, and the transfer and marketing of technologies to end-users.

# Limitations

The reduced per capita purchasing power of potential users of new products in most developing countries stands in contrast to the availability of very lucrative markets in the developed countries. This situation makes it less attractive for companies involved in biotechnology research to establish research facilities or subcontract research in developing countries. A few developing country governments, for example India and Brazil, have supported the public research apparatus to produce relevant products from biotechnology. They have been able to create and stimulate a scientific critical mass to capture the opportunities offered by the new scientific breakthroughs in biotechnology. In these countries, the emergence of an active private sector for the implementation of a sustainable research and development system based on entrepreneurship is still at an incipient stage. The development of business linkages between developed and developing countries remains a difficult and challenging task.

The absence in most of the developing countries of the necessary policy framework and the accompanying measures and regulations to promote biotechnology research and development is an area that limits the transfer of technology and business linkages. A small number of countries have recently adopted biosafety and intellectual property protection regulations. In most of these countries, these measures and regulations have been copied from the outside. Sometimes these regulations have been adopted without satisfactory participation from the local industrial and scientific community. In some of these countries, the approved measures and regulations have proven to be too costly to implement.

The high costs associated with biotechnology research, the lack of venture capital or public funding to support the development of the appropriate infrastructure, and the operating costs of the research itself in the developing countries are major limitations. It is clear that there is a tremendous gap between the amount spent on the development of products for the wealthiest people and the amount spent on products for the poor in developing countries. The Official Development Assistance (ODA) devoted to biotechnology through multinational instruments like the CGIAR centres in agriculture and the Tropical Disease Research (TDR) program in the health sector, although not negligible, is far from being sufficient to compensate for the lack of private capital.

The shortage of well-trained and experienced scientists is felt across the developing world. Often new Doctoral graduates are unable to find the necessary physical and intellectual environment to promote professional development and to acquire the necessary scientific experience. Successful scientists are often those who have adopted an aggressive entrepreneurial approach to obtain the resources necessary to achieve scientific results. Most of the trainees who have conducted their thesis work in developed country universities have had no exposure to enterprise development. In some cases, they have worked on themes of limited relevance for their own environment and are poorly prepared to face the realities of their own country.

# Future Options

The development of a critical mass of high-level motivated scientists is crucial in all countries. More resources from the development assistance agencies should be devoted not only to the training of these scientists but also to the building of appropriate physical environments where they can conduct their research. However, when a small country's economy is too small to generate the necessary critical mass of scientists, every effort should be made to generate multi-country initiatives to achieve efficient pooling of resources for the benefit of all countries involved. Great effort is needed to develop imaginative solutions that will reduce the negative impact of the brain drain and brain underemployment.

Entrepreneurs able and willing to capture the new opportunities offered by biotechnology must be encouraged and supported. It is the responsibility of the governments and their external assistance counterparts to create and support appropriate measures for entrepreneurial involvement in biotechnology research and development.

Within the context of scarce resources, it is important that research institutes and academic institutions take the necessary steps to identify the most relevant products for the target population. When defining policies, government officials should favour a participatory and dynamic process to define priorities and one that enables them to convert scientific results into industrial uses. A supply-led type of entry into biotechnology has been most common in developing countries and private sector involvement has generally been very low. With on-going structural adjustment programs in many developing countries and trends toward liberalization, there seems to be more interest in a market-led industry.

The stringent regulatory requirements in the developed countries contrast greatly with the weak or even non-existent regulatory requirements in the developing countries. This prevents developing countries from selling finished products to the developed countries or from participating actively in the field testing of products directed mainly at developed country clients. On the other hand, the shorter delays encountered in dealing with the regulatory system in developing countries could help accelerate the commercial production of products developed and marketed in and for developing countries. However, when the requirements for industrial production are too complex, many developing countries may not be able to manufacture at a low cost and may be forced to terminate their projects. Developing countries will likely find it advantageous to promote product innovation from less costly and less complex, but efficient, technologies.

External assistance programs should devote more resources to biotechnology in developing countries. However, the effectiveness of this assistance should be closely monitored particularly in terms of the impact and relevance of the research programs and projects. External assistance will be necessary for long-term as well as short-term programs if the increasing gap between North and South is to be reduced. Otherwise, biotechnology will continue to marginalize Third World economies. New international frameworks like the international agreement on the preservation of biodiversity should be adopted. This will help free some financial resources for biotechnology in the South where most of the biodiversity in the world is found.

Biotechnology can help resolve problems in the health sector of developing countries because health is the area in which most work is now taking place. Biotechnology can also have a great impact in agriculture, nutrition, and environment. Recent trends demonstrate that much of the gain in agricultural productivity in the developed world today originates from biotechnology. Another area that is still very much neglected and where a tremendous potential for progress exists is the energy sector. Biotechnology for energy should be given more attention. Nitrogen fixation, urban waste cycling, solar energy transformation, forest conservation, and many other areas pertaining to the energy sector should receive more attention.

# Discussion Summary

*Gaston Grenier*

*IIRSDA, B.P. V-51, Abidjan, Côte d'Ivoire*

## Developmental Recognition

Biotechnology has the potential to modify and improve the economic and social conditions of the population living in the developing world. On long term, it will create a new "revolution" in the agriculture worldwide. Biotechnology may well generate a greater impact in this sector than the so-called "agro-chemical revolution" in the 1960s and the 1970s. It will give the possibility to the developing countries to improve their self-reliance on adequate quantity and quality of food and to increase their competitiveness on the international commodity markets. Biotechnology has also the potential to resolve difficulties in the health as well as the energy sector of many developing countries or to help in the resolution of difficult problems such as the reduction of the population growth in some of the countries. However, in order to produce all these benefits, it is essential that appropriate policies and instruments be adopted in the developing countries themselves to promote research, development, and transfer of technologies and their marketing to the end users.

## Limitations to the Extension of Biotechnology in Developing Countries

The reduced per capita purchasing power of the potential users of new products in most of the developing countries stands in contrast with the availability of very lucrative markets in the developed countries. The situation in developing countries prevents the large multinational companies as well as the small ones involved in biotechnology research from implementing research facilities or sub-contracting research works in these countries. A few number of developing country governments such as India and Brazil have supported the public research apparatus to produce relevant products from biotechnology. They have been able to create and stimulate a scientific critical mass to capture the opportunities offered by new scientific breakthroughs in biotechnology. In these countries, the emergence of an active private sector for the implementation of a sustainable research and development system based on entrepreneurship is still very slow. The development of business linkages between developed and developing countries remains a difficult and challenging task.

The absence in most of the developing countries of the necessary policy framework and the accompanying measures and regulations to promote biotechnology research and development is another difficult area which limits largely the transfer of technology and the business linkages. A small number of countries have recently adapted biosafety and intellectual property protection regulations. In most of these countries, the measures and the regulations have been copied from outside. Sometimes these regulations have been adopted without satisfactory participation from the local industrial and scientific community. In some of these countries, the approved measures and regulations have proved to be too costly to be implemented.

The high costs associated with biotechnology research and the lack or venture capital or public savings to support the development of the appropriate infrastructure and the operating costs of the research itself in the developing countries are other major limitations. Although, no figures have been mentioned, the evidence exists of a tremendous gap between the amount of financial resources devoted to the development of products for the wealthiest population of the planet and the poor who live in the developing countries. This reflects the fact that the public opinion is more preoccupied by the rescue of its savings than by the social restructuring and rehabilitation of the world. The Official Development Assistance (ODA) devoted to biotechnology through multilateral instruments like the CGIAR centres in agriculture or the TDR programs in the health sector, although not negligible, are far from being sufficient to compensate for the lack of private capital.

The shortage of well trained and experimented scientists is felt across all the developing world. Often the new PhD graduates will be unable to find the necessary physical and intellectual environment to complete the development of their knowledge and acquire the necessary scientific experience. The successful scientists have often adapted an aggressive entrepreneurial approach to obtain the necessary resources to achieve scientific results. Most of the trainers who have conducted their thesis work in developed country universities have had no exposure to enterprise development. In some cases, they have worked on themes of limited relevance for their country environment and are poorly prepared to face the realities of their own country.

# Options for Better Benefits to the Developing Countries

The development of a critical mass of motivated scientists is a crucial element in all the countries. More resources from the development assistance agencies should be devoted not only to the training of these scientists but also to the building of appropriate physical environments where they can execute their research works. However, where the country economy is too small to generate the necessary critical mass of scientists, every effort should be made to generate multi-country initiatives in order to achieve an efficient pooling of the resources for the benefit of all the countries involved. Every effort and imaginative solution has to be found to reduce the negative impact of the brain drain and brain unemployment.

The development and support of new entrepreneurs able and willing to capture the new opportunities offered by the biotechnologies must take place. It is the responsibility of the governments and their external assistance counterparts to create and support the appropriate measures for entrepreneurial involvement in biotechnology research and development.

In a context of scarcity of resources, it is important that the research institutions and the academic institutions take the necessary steps to identify the most relevant products for the largest population. In their process to define the policy framework and the accompanying measures, the officials of the government should favour a participatory and dynamic process for priority delineation and for the conversion of scientific results into industrial use. The supply-led type entry into biotechnology has been the most common in developing countries and the private sector involvement has generally been very low. With the likely influence of the many on-going structural adjustment programs in developing countries and other trends toward liberalization, there seems to be more interest for an industry and a market-led type entry.

The stringent regulatory requirements in the developed countries contrast greatly with the weak or even non-existing regulatory requirements in the developing countries. The situation prevents the developing countries from selling finished products to the developed countries or to participate actively in the field testing of products directed mainly at developed country clients. On the other hand, the shorter delays encountered in dealing with the regulatory system in the developing countries could help accelerate the commercial production of products developed and marketed in and for developing countries. However, when the requirements for industrial production are too complex, the developing countries may not be able to manufacture at low cost and may be forced to terminate their projects. The developing countries will find advantageous to promote product innovation from less costly and complex technologies.

The external assistance programs should devote more resources to biotechnology for developing countries. However, the effectiveness of this assistance should be closely monitored particularly in term of the impact and the relevance of the research programs and projects. External assistance will be necessary for long term as well as short term programs if the speed at which increase the gap between the North and the South has to be reduce. Biotechnology will continue to marginalize the Third World country economies. New international frameworks like the international agreement on the preservation of biodiversity should be adopted to free some financial resources for biotechnology in the South where is located most of the biodiversity of the planet. There is a very close link between biodiversity and biotechnology.

Biotechnology can help resolve problems in the health sector of the developing countries. Health is the sector where most of the action is taking place. Biotechnology can also be of great help in agriculture and nutrition. As recent trends demonstrate, a great part of the gains in productivity of agriculture in the developed world today originates from biotechnology. Another area which is still very neglected and where there exist a tremendous potential for progress is the energy sector. Biotechnology for energy should be given more attention. Nitrogen fixation, urban waste recycling, solar energy transformation, forest conservation and many other areas pertaining to the energy sector should receive more attention.

Given the importance of the issues at stake and the complexity of the problems confronting the development of biotechnology in the developing countries, it was the panel opinion that IDRC should keep open the possibility of assembling a more permanent small group of experts to help reflect on how IDRC and other similar bodies could adjust their policies and programs to let the developing country populations, particularly the poor, access some of the benefits of the new biotechnology.

# Biotechnology in India

*G.P. Talwar and Rahul Pal*

*National Institute of Immunology, New Delhi, India, 110067*

## Abstract

*Biotechnology, which seeks to generate new technologies using the concepts and tools of modern biology has wide ramifications, with applications, amongst others, to agriculture, biomass production, aquaculture, animal productivity, and human health care. The nature and dimensions of problems in the developing countries are such that they call for new technological solutions, where biotechnology can play an important role. Biotechnology is nonpolluting and environment friendly. While it demands sophisticated scientific inputs, its applications in many instances do not call for huge layouts. The benefit, say in agriculture, is spread to large populations. It can help increase incomes and improve living standards.*

*Biotechnology development in India is for the time being entirely state supported. The organization and the working of a new Department under the Ministry of Science and Technology will be briefly described. During its brief existence (6 years), notable achievements have been made in several fields.*

*Two new National Institutions devoted to Immunology and Tissue Culture have been established. Also established are seven units in existing Institutions offering facilities for oligonucleotide synthesis, blue-green algae collection, microbial type and fermentation technology and supply of animals of defined genetic traits. Nineteen Institutions offer 2 year course leading to Masters in Biotechnology. A chain of Informatics Centres equipped with appropriate computers has been established in several Institutions, which are interlinked and connected through Satellite to International Data bases and Libraries.*

*In the agriculture field, emphasis is on selection of good varieties and large scale availability of biofertilizers, algae, rhizobium. Biopesticides for control of cotton destroying insects and bacilli secreting larvicides for mosquito control are in field trials with beneficial results. Culture of oil palm is now spread on 1000 hectares in more than one district as demonstration plantation. Better varieties of tissue culture grown cardamom has enhanced the yield several times. Elite tree plantlets of eucalyptus, teak wood, bamboos are being made available in large number to promote biomass production and afforestation. Experimental*

*approaches have been refined to induce breeding of fishes by LHRH analogues, and the cultivation of prawns with biotechnology inputs has enhanced the yield to 8.5 to 10 tonnes/hectare/year.*

*Cattle herd improvement is being achieved by a two pronged strategy. An injectable (TRLSUR) has been developed which sterilizes male bulls without loss of vigour for draught and traction purposes. This will help stop the proliferation of low genetic stock poor productivity animals. At the same time, these bulls act as sensors for detection of estrus, enhancing success of insemination with high genetic stock semen. Employing super ovulation and non surgical embryo transfers, a nursery of elite animals can be created. Of interest is the standardization of Desi stray cows to serve as surrogate mothers for gestation of high quality calves.*

*Employing hybridoma technology, highly accurate and simple to use diagnostic kits have been developed for amoebiosia, typhoid, filariasis, and hepatitis besides indigenous low cost kits for pregnancy, blood groups. Kits are under development for tuberculosis, leprosy, malaria, and Streptococcus A. These are expected to be of great help in correct and early diagnosis of widely prevalent diseases and provision of timely rational treatment.*

*A vaccine with remarkable immuno-therapeutic properties for leprosy is in Phase III field trials. It shortens not only the period for cure of multibacillary patients, thereby saving cost of medical care, drugs and better patient compliance, but it also upgrades the immune responses of these deficient patients to resist relapses on reinfection.*

*A major problem of India (and all developing countries) is the rate of population growth, which decimates largely the increase in food production and other amenities. India has currently 16% of the World Population with only 2% of global area. To the 875 million, 69,000 people are added every day. A novel category of vaccines for control of fertility are being developed. One of these, directed against the pregnancy hormone, has just completed the first leg of Phase II clinical trials, in which its ability to protect against pregnancy has been demonstrated. Earlier the safety, reversibility and lack of side effects of this vaccine were determined by a series of Phase I clinical trials in India and four other countries. Although much more work remains to be done before the vaccine reaches general public use, the first birth control vaccine is on the horizon. Incidentally these researches received critical grant support from the IDRC of Canada. Ancillary developments, namely two potential products for control of fertility by use of purified extracts of Neem, which have contraceptive and also antimicrobial and anti viral action are of conjoint interest. A recombinant version of the birth control vaccine is also under development, which would be considerably cheaper and amenable to mass scale use.*

Biotechnology seeks to generate new technologies using the concepts and methods of modern biology. It has wide ramifications with applications of benefit to agriculture, aquaculture, animal productivity and human health care. Although the roots of this technology are ancient and have been employed in fermentation processes for many years, the "new biotechnology" has emerged only about 15 years ago. With its immense potential and useful applications, it has attracted world wide attention. It is of particular benefit to developing countries where the nature and dimensions of problems call for new technological solutions. Biotechnology is multidisciplinary and interactive; its practice. however, in many. instances does not require huge layouts.

In India, the biotechnology effort is primarily supported by government funds. The Government of India constituted the National Biotechnology Board in 1982. and the Department of Biotechnology (DBT) was started as part of the Ministry of Science and Technology in 1986. The Prime Minister is the Union Minister for science and Technology. DBT is headed by a Secretary who is an eminent scientist. The Department has the usual government structure, although many positions are manned by scientists over and above those handling administrative responsibilities. The Department has constituted national and overseas Scientific Advisory Committees. It has set up 13 Task Forces in the areas of (i) Plant Molecular and Agriculture Biotechnology, (ii) Biological Pest Control, (iii) Fuel, Fodder, Biomass, Horticulture, Plantation Crops and Sericulture, (iv) Environmental Biotechnology, (v) Aquaculture and Marine Biotechnology, (vi) Veterinary Biotechnology, (vii) Medical Biotechnology, (viii) Biochemical Engineering, Downstream Processing and Instrumentation, (ix) Microbial Biotechnology, (x) Industrial Biotechnology, (xi) Basic Research, Emerging Areas and R&D Facilities, (xii) Bioinformatics, and (xiii) Integrated Manpower Development. DBT started with a budget of Rs. 142 crores in the 7th Plan (1985-1990). The projected budget for the period 1992-1997 is Rs. 650 crores (a crore = 10 million).

The Department has undertaken and supported several programmes. Two Institutions have been established with the core budget from DBT. These are the National Institute of Immunology (NII), New Delhi and the National Facility for Animal Tissue L Cell Culture (NFATCC). Pune, which are both premier institutions of the country.

Infrastructural facilities have also been set up for oligonucleotide synthesis at the Indian Institute of Science, (IISC) Bangalore, the CSIR Centre for Biochemicals, New Delhi and the Centre for Cellular and Molecular Biology (CCMB), Hyderabad. National Facilities on Microbial Type Culture Collection a; the Institute of Microbial Technology (IMTECH) Chandigarh, and on Blue Green Algal Collection at the Indian Agricultural Research Institute (IARI), Delhi, have also been set up. A National Animal House Facility has been established at the Central Drug Research Institute (CDRI), Lucknow and the National Institute of Nutrition (NIN), Hyderabad. These facilities have been created or upgraded in existing institutions.

For manpower training, DBT has started MSc. Biotechnology courses in 19 universities/institutions of the country. These programmes attract some of the brightest students in India. The course content and training programmes are of an inspirational and stimulatory nature. DBT has also instituted short term training courses, of 2-4 weeks duration, in biotechnology with the aim of providing hands-on experience in areas of modern biotechnology to mid-career scientists. About 1200 scientists have so far been trained in various techniques. In addition. the Department awards 20-25 Post Doctoral Associateships every year, enabling scientists to undergo training at other National Institutes on relevant research projects. Short term (3 months) and long term (1 year, extendible to 2 years) overseas Associateships are also awarded to scientists holding regular positions, for pursuance of advanced research in high priority areas.

DBT has established a national network for information relating to biotechnology which connects several important centres in the country. The Apex Centre of the Biotechnology Information System is located at DBT and is associated with nine Distributed Information Centres (DICs) established at various R&D laboratories, which store and disseminate information in the areas of (i) Genetic Engineering, (ii) Animal Cell and Virology Culture, (iii) Plant Tissue Culture, Photosynthesis and Plant Molecular Biology, (iv) Oncogenes, Reproduction Physiology, Cell Transformation, Nucleic Acid and Protein Sequences, (v) Immunology, (vi) Enzyme Engineering, Immobilized Biocatalysts, Microbial Fermentation and Bioprocess Engineering. DICs also interact with Distributed Information Sub-Centres established at different locations of the country. All DICs are inter-connected via satellite through the National Informatics Centre Network (NICNET). Besides providing access to databases such as MEDLAR, as well as updated information on international patents, NICNET also provides on-line access to international databases such as the Brookhaven protein Data Bank and the Cambridge Structural Data Base on X-ray and Neutron Studies. This set-up has in a short time revolutionized the access of the scientist to biotechnology related information within and outside the country.

Research projects supported by DBT are located in various institutes of the country. Progress is monitored by Scientific Monitoring Committees meeting at least once a year and sometimes more frequently. Site visits are conducted for major projects. Some of the achievements made during the last five years of the existence of DBT are summarized below, particularly those which bear relevance to problems of developing countries.

# Agriculture

The current production of food grains is about 170 million tonnes/year. Based on current trends of population increase, the requirement by the year 2000 is projected to be 250 million tonnes/year. This would call for evolving strategies for the integrated management: of water and soil resources. While the Indian Council of Agricultural Research (ICAR) is primarily involved with the development of new varieties of seeds, several important elements contributing to our efforts to achieve the requisite target of food production are being supported by DBT. These pertain to the development of biofertilizers, biopesticides and to the cultivation of oil palm. DBT has also supported programmes that aim at increasing the production of cardamom and other cash crops.

## Biomass Production

The forest cover of India has dwindled and currently stands at 11%. For ecological reasons, as well as for the provision of wood for fuel and for meeting industrial need for paper, an intensive programme of biomass cultivation has been initiated. Biotechnology offers a unique opportunity in this are - the ability to cultivate an elite tree in a test tube. Two pilot plant units for research and development in plant tissue culture techniques and for mass production of saplings have been set up at the National Chemical Laboratory (NCL), Pune and the Tata Energy Research Institute (TERI), New Delhi. Plantlets of two species of bamboos, Dendrocalamus strictus and Bambusa arundinacea have been grown using these techniques. 7000 plantlets have been transferred to field status in the states of Uttar Pradesh, Orissa, Karnataka and Delhi and are being evaluated with regard to their growth characteristics. Tissue culture technologies are also being developed for mass propagation of important forest trees like. eucalyptus, teak and sandalwood.

## Cardamom

This spice has a high export potential, but yields in the country have only been of the order of 60 Kg/hectare, about a quarter of what has is achieved in some other areas of the world. Field trials using elite tissue culture developed clones have been initiated in several cardamom growing regions.

## Edible Oils

The country's requirement for edible oils far exceeds production, necessitating imports worth several hundred crores of Rupees per year. Palm oil constitutes a major portion of these imports. Oil palm yields are the highest amongst the edible oil producing crops, being about 4-6 tonnes/hectare. Imported and indigenous seeds have been planted over areas of a 1000 hectares each to demonstrate the feasibility of oil palm cultivation under irrigated conditions. In addition, efforts to propagate oil palm using tissue culture techniques are also underway.

## Biofertilizers

To achieve high yields, adequate nutrients have to be supplied to crops. Nitrogen, essential for sustained growth, has conventionally been provided by chemical fertilizers, made using expensive, energy-intensive processes. The use of biologically-fixed nitrogen thus has obvious appeal. About 140 million tonnes of nitrogen are added annually to the earth's surface by nitrogen fixing organisms. The National Facility for Blue Green Algal Collection at New Delhi collects, screens and identifies new nitrogen fixing blue-green algal (Cyanobacteria) strains which can be used to enrich soils used for cultivation of rice, pulses and oil-seeds, with the ultimate aim of reducing dependence on chemical fertilizers. Research in this area is also being carried out at the Madurai Kamaraj University, Madurai, the Tamil Nadu Agricultural University, Coimbatore, the College of Agriculture, Pune, the Council of Science and Technology, Lucknow and the Sri Ramakrishna Ashram, Nimpith.

Blue-green algae have been tested for their ability to provide nitrogen inputs in the rice ecosystem. Inoculation of the algal culture is normally done seven days after transplantation. Field trials have shown that algal inoculation contributes to an increased yield of 5-14 %. Studies have shown that the amount of chemical fertilizers required for optimum yields is considerably reduced in fields where algal inoculations have been carried out. Algae have several other ecological advantages. They have the ability to concentrate nutrients such as Nitrogen, Phosphorus, Carbon and other trace elements. They can also scavenge sodium and are therefore beneficial in salt-affected soils.

Rhizobium strains are being developed and tested at the National Facility for Rhizobium Germplasm Collection, New Delhi and will be supplied to different laboratories for field trials. Success has been achieved in growing some of these strains in fermenters. Laboratory testing for nodulation in a variety of pulses, groundnut and soyabean are in progress.

## Biopesticides

Insects and crop diseases result in significant drops in yields. Chemical insecticides and pesticides, in addition to being expensive, are frequently absorbed by plants and transmitted down the food chain, with potentially harmful consequences. In addition, a certain degree of tolerance often develops to many of these agents, necessitating the use of higher doses. The search for new, environmentally-friendly agents is therefore of paramount importance. biological control agents have been developed and field tested, with the aim of selectively destroying crop pests. These are: (i) Baculoviruses - Nuclear Polyhedrosis Viruses (NPVs, for the control of Heliothis armigera and Spodoptera litura); (ii) Parasites and predators - Chysopa (for the control of aphids, white flies and bollworms); Trichogramma (for the control of Lepidopteran pests; and (iii) Fungal/Bacterial Antagonists - Trichoderma, T. harzianum, T. koningi, Gliocladium virens and B. subtilis.

These biocontrol agents, alone or in combination, have shown promise in cotton, chickpea, sugarcane, groundnut, cauliflower and tobacco cultivations in field trials carried out over a total plantation area of 1000 hectares. In particular, the sequential release of Trichogamma, Crysopa and the two NWs resulted in higher yields of groundnuts.

# Aquaculture

In order to increase significantly the breeding of freshwater fish, a hormonal approach involving the use of synthetic GnRH analogs has been developed at the National Institute of Immunology (NII), New Delhi. Injection of microgram quantities of such analogs which can be synthesized in abundant quantities, induced breeding of cat fish, carps. and major carps. The hormonal treatment can be repeated every few months in temperature and photoperiod controlled hatcheries, making possible the off-season breeding of these fishes in large numbers. These technologies have been field-tested in fish farms in Tuticorin and Manimuthar, Tamil Nadu.

Biotechnological inputs have helped increase prawn yields to 8.5 tonnes/hectare/year in Andhra Pradesh and Orissa, using semi-intensive farming techniques. The project aims at obtaining yields of 10 tonnes/hectare/year for two successive years. Future plans include standardization of in vitro fertilization techniques and long-term cryopreservation of prawn larvae.

A programme for the development of growth hormone transgenic fish is underway at Madurai Kamaraj University in efforts to achieve an enhanced growth rate, using Tilapia and Zebra fish as model systems.

# Cattle Herd Improvement

India has nearly 300 million cattle. More than two-thirds of this vast number are low productivity animals. Religious beliefs do not permit their slaughter. An injectable agent has been developed at NII which sterilizes male animals without loss of libido. This invention has received the New Drug Authorization and has been recently licensed to a company in Bangalore. It is being marketed under the trade name "Talsur". Talsur renders the bulls azoospermic. As testosterone levels do not fall, these animals can be employed as biosensors or "teaser" bulls to detect females in heat. This is particularly useful in buffaloes where the estrus is silent. As the fertile life of the egg is one or two days, detection of ovulation is important for timely insemination. The availability of such teaser bulls will therefore be of special utility for animal husbandry of buffaloes which constitute the backbone of the white revolution. Talsur has thus the dual benefit of controlling the proliferation of scrub animals and of being an important additive to A.I. programmes.

Another programme launched by the DBT is in embryo transfer technology (ETT) for cattle herd improvement. The programme has been conducted as a Science and Technology mission, with participation of National Dairy Development Board (NDDB), the National Dairy Research Institute (NDRI), Indian Veterinary Research Institute (IVRI), and the National Institute of Immunology (NII). The objective of the project was to create a nursery of elite animals. By this technology, high milk-yielding cows or buffaloes could engender up to 150 calves instead of 6 - 8 achievable by traditional breeding practices. The technology comprises of hormonally superovulating elite donor animals, obtaining embryos nonsurgically by flushing and their non-surgical transfer to animals of low genetic quality. Another important benefit of ETT is the employment of local stray cows of low productivity as a surrogate mothers to produce high genetic stock animals. The project has been highly successful. Embryo banks have been established at several places. Techniques have been developed for obtaining higher yields of embryos per flush in both cows and buffaloes. Genetically identical twins have been obtained by transfer of embryos split by micromanipulation, doubling in a way the overall yield. The project would seek in the next five years to develop technologies for obtaining eggs without the use of exogenous hormones, their in vitro maturation and fertilization. Transgenic animals will be developed by insertion of genes far desirable products such as erythropoeitin. Techniques will be further refined and evaluated for sexing and cloning of embryos.

# Human Health

Biotechnology has ushered in new possibilities for products and processes additive to human health care. Human growth hormone (hGH) has been prepared in abundant quantities by recombinant DNA techniques. The hormone from beef or pork is not usable in humans due to species restrictions. Before it was available from the genetic engineering route, the only source was extraction from cadaver pituitaries, evidently a meagre source for general supply. A genetically engineered vaccine to prevent Hepatitis B infection is also in the market after due clinical and safety trials. Other recombinant DNA products which have already reached the market are human insulin, a and 7 interferons, tissue plasminogen activator, erythropoeitin etc. The list is growing. Much of this progress has for the time being taken place in industrially developed countries. The developing countries are also entering this arena. At NII, we have obtained the B chain of cholera toxin/heat labile enterotoxin in large yields, employing a mutant bacterial expression system. Work is at an advanced stage for obtaining hGH as well buffalo growth hormone. The latter increases the milk yield of buffaloes by about 20% and also results in a better feed conversion quotient. We are also working on efficient expression of the u and P subunits of human chorionic gonadotropin (hCG) in an insect expression system.

## Immunodiagnostics

Hybridoma technology enables the production in unlimited amounts of antibodies of defined characteristics. These in turn are the key reagents for developing accurate, sensitive but simple to use methods for diagnosis. At NII, diagnostic kits have been developed for both invasive and enteric amoebiasis. The tests are rugged, with a shelf of about a year. The diagnosis is available in the form of a colour change on a dip-stick in 35 minutes, employing a drop of finger prick blood. According to the WHO, 10% of the world population carries amoeba and 1/10th of these individuals suffer from clinical disease. Another unique test developed at NII is for the diagnosis typhoid. Hitherto, the Widal test commonly employed in laboratories could provide indications only 8-10 days after the onset of pyrexia. Our new test provides the right diagnosis on day 1, enabling the quick initiation of chemotherapy. What is more, the kit combines a drug sensitivity test which provides indications on the optimum choice of drug(s) for treatment of a given patient. The drug sensitivity test is now becoming necessary in view of the wide spread resistance of Salmonella to habitual drugs. Both these tests have been licensed to Industry after extensive Institutional and field testing. They would be useful not only in India but also in other parts of the world where these diseases are rampant. Other kits which have been developed can help in diagnosis of filaria and leishmania. The NII has also developed highly specific tests for the detection of M. tuberculosis and Hepatitis B, employing DNA probes +/- PCR. Tuberculosis is the major disease in India, with 2 million new patients and half a million deaths every year.

An Immunotherapeutic/Immunoprophylactic vaccine for Leprosy: India has the world's largest number of leprosy patients. These 4 million patients are spread all over the country and cannot be logistically isolated on an island, as could be done in Japan. The disease manifests itself as a clinical spectrum related to the immune status of the patient. Multibacillary lepromatous leprosy (LL) patients have the extreme deficit and do not exhibit cell mediated immune responses to M. leprae. The bacilli proliferate in their tissues and spread' as an infection to others. For all practical purposes, these patients constitute the reservoir of the infection. Like small pox, it is theoretically possible to eradicate leprosy if the immune responses of these patients can be upgraded so that they do not serve as hospitable territory for bacterial growth. In fact, 99% or more of humans in endemic ares with normal immune apparatus can resist infection.

About 14 years ago, we were able to develop a candidate vaccine which could invigorate immunity in deficient LL patients. The vaccine employs a killed suspension of a nonpathogenic soil mycobacteria which shares antigens with M. leprae and M. tuberculosis. This vaccine is currently in large scale Phase III trials. In two hospitals in Delhi, it has been used for the treatment of multibacillary patients as an adjunct to multi drug therapy (MDT). Multibacillary LL patients take 2-5 years of treatment with MDT to become bacteriologically negative. Inclusion of the vaccine once every 3 months shortens the recovery period significantly. What is more, vaccination converts 80% of these patients to a status of lepromin positivity, which drugs alone do not bring about. The vaccine has also been effective in drug resistant patients. This vaccine is currently in field trials in Kanpur District in a population of 362,000, in collaboration with the National Leprosy Eradication Programme.

## New Methods for Fertility Control

India's population is increasing at the rate of 2.1%, which means that more than 17 million are added every year to an already large figure of 876 million. 69,000 people are added every day. Control of population is a priority of the country and for that matter, of the entire developing world. Several factors such as education, status of women, regulation of child labour, general level of economic development would no doubt influence the acceptance of family planning methods. However, there is also need for socio-culturally acceptable methods with low user-failure risk. Our group has been involved with the development of birth control vaccines. These methods would require periodic intake and if properly designed, would not interfere in the normal physiology of the non-pregnant female. Steroidal contraception, though highly effective, blocks ovulation and provides synthetic female hormones exogenously.

The vaccine which is at present at the most advanced stage of development is directed against hCG, a hormone which is made in appreciable amounts only in situations of pregnancy or some cancers. If is an early signal of conception and is important for the establishment and sustenance of pregnancy. The rationale of the vaccine is to induce the formation of antibodies which can inactivate hCG as and when it is formed. Thus, corpus luteum function is not sustained and the woman menstruates even if fertilization has taken place. hCG is self hormone and would not by itself cause the formation of antibodies. It was rendered immunogenic by tagging the P subunit of hCG to a carrier such as TT (the a subunit is not employed for vaccination purposes for fear of undesirable cross-reactivity to follicle stimulating hormone and thyroid stimulating hormone, which share this subunit). This structured vaccine engendered antibodies against both hCG and TT, the latter providing protection against tetanus. a largely prevalent mortal infection at the time of delivery.

The vaccine has undergone extensive safety studies. Being the first vaccine of its type, a series of toxicology studies. including life-long toxicity studied in monkeys, were carried out to establish the safety and reversibility of the vaccine. phase I clinical trials with this vaccine were conducted in 9 centres in India, Finland, Sweden, Chile and Brazil. These studies demonstrated that the vaccine was immunogenic. Menstrual regularity was maintained and ovulation remained undisturbed. Clinical chemistry and haematological parameters in immunized women were normal and there was no evidence of immunopathological reactivities. The vaccine was reversible in every case.

Phase II efficacy trials have been carried out in 3 major Institutions of the country. The main objective of these trials is to determine whether women of proven fertility can be protected from pregnancy by immunization with this vaccine. If so, the trial seeks to determine the level of antibody titres necessary to prevent pregnancy. As on March 31, 1992, 752 protected cycles were recorded in highly fertile women, with only one pregnancy having taken place at antibody titres greater than 50 ng/ml. Several women were exposed to the risk of pregnancy for periods ranging from 12-22 months. This is first time anywhere in the world that a birth control vaccine has been clinically tested to be effective in preventing pregnancy.

These trials have demonstrated that the vaccine is protective in principle. To make it a logistically usable product, however, further refinements would be necessary. The following strategies are under investigation:

(i) During primary immunization, a woman has to receive 3 injections of the vaccine at 6 weekly intervals to attain antibody titres beyond the protective threshold. It is necessary to provide reliable contraception during this period by an ancillary approach which does not interfere with the immunological response against the vaccine. Our group has prepared a purified extract from the Neem tree (Praneem), which, after a single application in the uterus, prevents pregnancy for at least 3 months without effecting ovulation and hormonal profiles. The treatment is akin to a vaccine, inducing locally cell mediated immunity (VILLI). Acute and subacute toxicology studies have been completed with VILLI. An application has been made to the Drugs Controller of India for permission to start a Phase IIb clinical trial combining VILLI and the hCG vaccine. Research on Praneem has also given rise to a polyherbal vaginal cream and pessary with dual properties of contraception and anti-microbial and antifungal action. These preparations have entered Phase I clinical trials in China, Nigeria and Brazil under the South-to-South Collaborative Programme.

(ii) It would be desirable to administer multiple doses of the vaccine at a single contact point. Biodegradable microspheres are under development, which can release the entrapped vaccine over a period of time to generate antibody responses similar to or better than those obtained by conventional multiple immunizations.

(iii) A vaccinia virus based anti-hCG vaccine has also been developed which is highly immunogenic in rodents and primates. The use of vaccinia or related viruses for anti-hCG immunizations in women may not only help reduce the frequency of injections, but will also bring down considerably the cost of the fertility control vaccine. Clinical trials of a recombinant vaccinia hCG vaccine virus have started in patients of non-small cell carcinoma of the lung. This cancer makes hCG and its subunits which are autocrine growth factors for the proliferation of tumour cells. No effective chemotherapy exists for this type of the disease at present.

Although vaccinia based vaccines for HIV have been approved for Phase I trials in humans, and vaccinia rabies and rinderpest vaccines are in use in animals, it may be necessary to develop a recombinant vaccine that does not replicate in humans. Fowl pox viruses are worthy of investigation as vectors for a recombinant fertility control vaccine.

It may be appropriate to acknowledge that the International Development Research Centre (IDRC), Canada provided supported for the development of the hCG vaccine from the early stages when it was a novel and venturesome idea. Thanks to this support, the work could proceed and reach the present stage where the hCG vaccine appears to be a reality.

Many laboratories all over the world are today engaged in the development of fertility control vaccines. Besides hCG, vaccines are also under development against follicle stimulating hormone (FSH, for the control of male fertility), luteinizing hormone releasing hormone (LHRH. as a post partum contraceptive for the extension of lactational ammenohorea) and against sperm and zona pellucida antigens. The LHRH vaccine has undergone early Phase I trials; the FSH vaccine is due to enter Phase I trials soon. Other vaccines are currently at the experimental stage. Hopefully, many of them would become workable propositions.

In view of the fact that immune responses are genetically regulated. no single vaccine may work in all recipients. To obtain near to 100% response, it may be necessary to employ poly-vaccines which target more than one reproductive tract antigen.

# Development of Biotechnology in Asia

*Setijati D. Sastrapradja*

*Center for Research in Biotechnology, Jalan Juanda 18, P.O. Box 323, Bogor, Indonesia*

## Abstract

*National development of the developing countries in Asia is challenged with similar problems in the decades to come. Population pressure, food and nutrition insufficiency, environmental degradation, job creation, are just a handful of realities that most of them should face. Therefore, any energy technology which promises hopes such as that of biotechnology, is greeted with enthusiasm. This paper is reviewing what happened in Asia as far as biotechnology is concerned. Of the many opportunities shown in various international and regional fora, it seems that the region of Asia has comparative advantages in developing agricultural biotechnology. Lack of trained manpower in the field of molecular biology and financial resources are identified as common phenomena. Another serious constraint is the weak linkages among research institutes. In most countries, the public sector is the leading actor with little participation from the private sector, if any. Development assistance has been received from various donors. The effectiveness of such assistance, however, should be evaluated if biotechnology is aimed at its application. Linked with this application is the question of the Intellectual Property Rights and the issues of biological material ownership. Finally, it is hoped that sustainable efforts should be attempted to guarantee its long time results.*

## Introduction

In recent years new cluster of technologies have emerged propelling further the progress of industries in the developed countries. Biotechnology is identified as one of that cluster which plays a leading role (Colombo, 1991). With biotechnology, low volume high cost new products, clean and faster bioprocesses and environmental services are promised. Because of its bright application potentials and because of its intense advertisement, biotechnology is the topic of the day discussion, not only in the developed countries, but also in the developing countries. Asian region is not exempted from such an enthusiasm.

In term of economic development, the status of the countries in Asia varies. Some are considered as well developed, but some belong to the lowest income group. Population wise, three countries in Asia are among the four largest nations in the world. Many countries in Asia, fortunately, are rich in biological diversity. Traditionally, this diversity has been employed to fulfil the basic needs of the people. Moreover, part of the states income derives from agricultural commodities which are nothing but biological resources. In employing the biological resources, technologies are indeed important. On the contrary, certain technologies such as that of biotechnology need biological resources for their advancement. The reciprocal dependency of biotechnology and biological resources is sometimes overlooked.

Several regional fora of biotechnology have been organized in Asia. The topics for discussion vary ranging from policy development, technical matters, to public awareness. This paper reviews what have been done in Asia as far as biotechnology is concerned, the opportunities it offers and the limitations it has. Special reference is given to the most populated countries, i.e. China, India, and Indonesia, in which agriculture plays an important role on their economy.

## Why the Enthusiasm?

Every year the World Resource Institute, together with UNDP and UNEP, produces a publication on World Resources. Based on the data presented for 1990 - 1991, it was obvious that the world's population is still growing. Compared to other regions of the world, Asia is the most populated region. The estimated figures for 1985 were: China 1,000.9 million, India 754.6 million, and Indonesia 166.0 million (WRI, 1990 - 1991). Further it was stated that the annual rate of increase for Asia was 1.85%, which is higher than the world average (1.73%). The projected figures for 2025 are: China 1,492.6 million, India 1,445.6 million, and Indonesia 263.3, with the average annual population changes are 1.39%, 2.08%, and 1.62%, respectively for the period of 1985 - 1990. The average of Asia for that period is 1.85%. It means that India is above the Asian average and thus its projected number for 2025 is closer to China. The increase of the number of population is not necessarily followed by the increase of the quality of life.

One of the indicators of development is life expectancy at birth. In all countries of Asia, life expectancy has risen from 53.3 in 1965 - 1970 to 61.1 in 1985 - 1990. However, there are countries which are under this average. India, Indonesia, Nepal, and Pakistan are among these countries. Another indicator is income. *Caring for the Earth* (1991) lists 160 countries with lower income, middle income and upper income. Most countries in Asia fall into low income or lower middle income. Only a few are categorized into high income countries. Among the last group, belong Japan, Hongkong, Singapore, and Brunei. Though quality of life has risen in Asia, poverty has not been washed out completely. It is true that world food production, especially in developing countries, has increase remarkably during the past 23 years. The success was achieved, among others, through the application of high yielding varieties and the fertilizers/pesticides they required. Moreover, arable land was available for the expansion of land under cultivation. Food production to meet the needs of the increasing population faces new challenges (Brady, 1990; Swaminathan, 1991). Under present agricultural practices, there is a sign that production of high yielding varieties is beginning to level off. Arable land in some developing countries is no longer easy to be found, forcing the farmers to use more marginal land. Meanwhile, excessive application of fertilizers and pesticides in many developing countries has degraded the environment. To meet with these challenges, new appropriate technologies are required; hence, the enthusiasm of the developing countries to join the world community in their endeavour to speed up the application of biotechnology for agricultural development.

For many developing countries in Asia, agriculture is not only to produce food, but also to earn foreign exchange. For centuries, countries like India, Indonesia, Sri Lanka, and Malaysia are the exporters of agricultural commodities. Large area in Asia are occupied by plantation of oil palm, tea, coffee, cacao, sugar cane, cotton, etc. Production technology for those commodities are well developed. To compete in the world market, however, technology for processing should be refined from time to time. The market of natural sugar is greatly reduced due to the application of biotechnology for sweetener production (Hobbelink, 1991). The next target is cacao market. Realizing the threat, the developing countries in Asia are more than eager to grasp biotechnology to increase the added value of their commodities.

Asia is also home of medicinal plants which have been used traditionally to maintain health and cure illness. Pharmaceutical industries are in the need of the products of those species to be processed further into high value substances. In addition to this group of species, there are species which are sought for cosmetic industries. Industrial application for pharmaceutical or cosmetic products will certainly affect the developing countries either positively or negatively.

That many countries in Asia are rich in biological resources was highlighted recently when the world community expressed their concern on their fast erosion. Of the twelve Vavilovian centers of economic plants, four are located in Asia (Zeven and Zhukovsky, 1975). Many of these species have not been improved scientifically. Several of them have limited distribution and valuable only to the local communities. The adapted values of the traditional varieties to local condition are important component to developing new varieties for specific purposes. Biotechnology is of a great help to identify the desired characters. Moreover, biotechnology shorten the period needed for incorporating the characters into a new combination. Such a specific goal may escape from the global interest. Besides, the problems can only be solved where they exist.

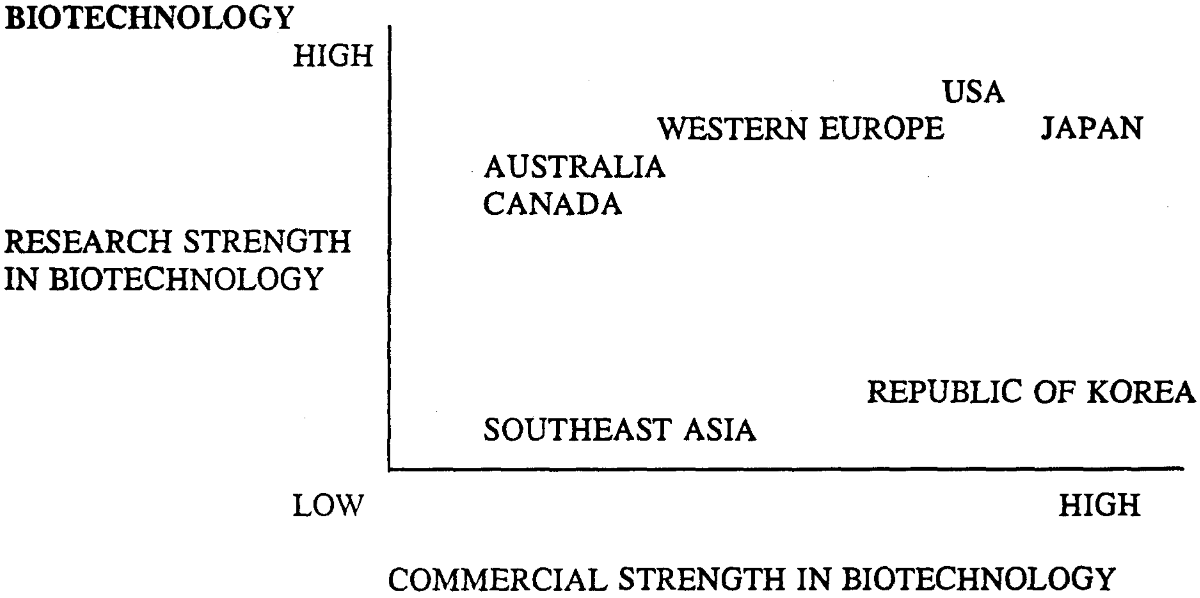
Linked with the biological resources are the forest resources in which myriads of plants, animals and microbes live. It is well noted that the world's forest has declined with time especially that in the tropics. Agricultural expansion, wood extraction, resettlement program are among the causes of the decline. Accelerated change in forest areas of the tropics has occurred throughout the 1980's. In Asia, the notable reduction of forest areas are in India, Indonesia, Myanmar, the Philippines, and Thailand (WRI, 1991). Indonesia and Malaysia, for example, are the home of dipterocarps - timber species - which many of the species are endemic to this region. Species endemism is also true for animals. With the go of the dipterocarp family, also gone the animal species and others which economically are unknown yet. What left behind is the barren land needed to be reforested. This, in turn, requires millions of planting materials, which through traditional propagation means are hardly sufficient. The potential of biotechnology for rapid multiplication of the desired species give hope. Moreover, through biotechnology the early selection of the species in which seeds are produced without difficulty can be accomplished. In short, Asia - together with the rest of the world - is welcoming the era of biotechnology with enthusiasm. There are many problems existing in Asia which biotechnology is expected to be of use in solving them. Therefore, activities in research have been initiated two decades ago mostly in the public sector.

# What Has Been Achieved in Asia?

Governments in Asia do believe that the application of biotechnology in industry, health and agriculture will soon be a reality. Therefore, research and development in biotechnology has been put as one of the priorities. Accordingly, every country in Asia, rich or poor, has initiated activities in biotechnology. Those countries which have advanced infrastructure and sufficient resources are ready to absorb the new techniques developed in this field. In no time the scientific community in these countries was able to master techniques such as gene cloning, gene transfer, DNA-finger printing, cell immobilization, etc. Other countries with much limited resources are struggling to make themselves not to be left behind.

To get an idea how strong the countries in Asia in biotechnology, Greenfield (1991) presented a table as follows:

**A PERCEPTION OF RELATIVE COMMERCIAL AND RESEARCH STRENGTH IN BIOTECHNOLOGY**




From the figure given, it is obvious that most Southeast Asian countries fall into low research strength and low commercial strength in biotechnologies. Japanese, being an industrial country, is comparable in rank to USA. There were 143 products in various stages of development were of biotechnology derived pharmaceutical products which were processed by a group of Japanese companies. Korea, on the other hand, has high commercial strength but its research strength is low. To improve this condition, a tripartite system of research and development, involving universities, government research institutes, and industries, has been developed (Chung, 1991). As many as 19 companies join efforts to conduct research and development in industrial biotechnology. Singapore, realizing that the world market is difficult to enter, through its Institute of Molecular and Cellular Biology (IMCB) has yet a joint venture research with GLAXO (Sercovich, 1991). In the field of medical biotechnology, Asia is aiming at the development of diagnostic kits and vaccines for major tropical diseases, such as hepatitis B and dengue fever. Research on various aspects of medical biotechnology has taken place in the public sector, especially in developing countries in Asia, in conjunction with the public health care. The Japanese institutes are again leading in this endeavour. A Chinese institute offered monoclonal antibodies against human T lymphocytes, for example (*Biotechnology and Development Review*, 1991). Most widely used technique in agricultural biotechnology is tissue culture. Commercially, it is used in the production of potato and flowers. Success in rapid multiplication of forest tree species, such as teak, acacias, and casuarinas, has been reported within the laboratory scale. The drawback of applying tissue culture for mass production of oil palm seedlings has also been reported. More sophisticated techniques, i.e. cell/and protoplast fusion, gene cloning, genetic engineering are at various stages of application. Japan, for example, has succeeded in regenerating 73 species from protoplast culture and 25 inter-species or intergeneric combination from fused cells. China is leading in the creation of new rice varieties through biotechnology (Zhensheng, 1991). He emphasized the need to combine biotechnology technique with conventional plant breeding practices.

Member countries of FAO regional Asia and Pacific in their 20th Conference (1990) had urged FAO to establish a regional cooperation network in plant biotechnology. To follow up that desire, FAO convened a regional expert consultation on the Role of Biotechnology in crop production the following year (1991). In this meeting, activities on plant biotechnology in the member countries were received. Despite the many research activities, only a small number of matured technologies generated through the use of biotechnologies could be shared at the regional level (Singh, 1990). Two priorities were identified: 1. micropropagation of oil palm, coconut, and date palm; and 2. development of Bt - technology in identified laboratories.

In addition to the two areas mentioned, improvement of grain legumes and oil seed crops through biotechnology was also discussed in detail. Among the progress made were distant promising hybrids in groundnut, diagnostic kits for identification of viruses in soybean and groundnut, as well as RFLP mapping in *Brassica* and soybean.

One important observation was made regarding the general notion that in developing countries, the region of Asia-Pacific is no exception, there were poor linkages among the different actors in biotechnology activities. These actors are research institutions, universities, government departments and industry. In the developed countries, most industries are in the hand of the private sectors. If research in biotechnology should be expected to reach the receiving ends, the complexity of the flow from research to commercialization should be realized. Such a complexity was highlighted by using maize research as an example (Brenner, 1991).

# The Role of the Private Sector

In developing countries, public sector plays dominant role in biotechnology activities. Almost in every country a national effort is aimed and quite often new institution was established just for biotechnology. To mention a few, a full-fledged Department of Biotechnology in the Ministry of Science and Technology was set up in 1986 by the Government of India; Indonesia has established a Center for Research in Biotechnology under the Indonesian Institute of Sciences; the Federal Ministry of Education of Pakistan has organized a National Centre of Excellence in Molecular Biology, and in Thailand a National Center for Genetic Engineering and Biotechnology (NCGEB) was organized in 1983. The driving force behind the commercialization of biotechnology is financial profit. From the history of commercial biotechnology we learned that the public sector was the place where biotechnology research started. The transfer to the private sector happened as soon as there was a sign of marketing opportunities (Hobbelink, 1991). No less than two-thirds of biotechnology spending comes from the private sector. The transnational corporations are the leading private sector in the field of biotechnology at present. In most developing countries in Asia, the private sector is weak. Indigenous industries prefer to buy technologies from the world market. Those belonging to transnational corporations draw most of the research and development needed for their manufacturing activities from their headquarters. There then is no urgent need for new technologies from the public sector, unless that condition is altered, allowing a better relationship between the public and private sector. The privatization of biotechnology products and processes leads to international debate on Intellectual Property Rights (FAO, 1991; UNEP, 1991; Keystone, 1991). None of the developing countries in Asia has Intellectual Property Rights on crop varieties and plant products. It was realized that biological resources are often considered a common heritage of mankind and thus should be freely accessible. Biotechnology is, on the other hand, a technology which can be patented and accessible only with cost. The developing countries are demanding the transfer of technology, including biotechnology in exchange of the biological materials they have (UNEP, 1991) free of charge. While the debate of IPR is still going on in UNEP, many believe that biotechnology will revolutionize agriculture production the way the Green Revolution did in early 1970's. To avoid the same mistake that the Green Revolution showed, i.e., it could not benefit the poor farmers, a dialogue on Biotechnology in Agriculture - Reaching the Unreached, was held in India in early 1991 (Swaminathan, 1991). Deo (1991) doubted the promise of biotechnology will mean much to small farmers in the developing world. These farmers are the ones who developed traditional varieties over times and this type of varieties are the raw materials for biotechnology. After several years of discussion, finally the concept of Farmer's Rights is officially recognized in FAO. With these rights, farmers all over the world will be compensated if their materials were developed into high value products. How this concept can be worked out and put it in practice, it certainly needs time. Another issue associated with biotechnology is the concern about the release of the genetically engineered organisms to environment (Riley, 1989). While it is true that the risks have not been, yet the assessment of the possible dangers should be taken into account. The industrialized countries are ready with the regulatory procedure for biotechnology products. Consequently, to obtain approval from the government is time consuming in the developed countries. Many developing countries in Asia, however, have not developed such regulatory procedures. There was fear that these countries may become the experimental ground for releasing the genetically engineered organisms by foreign industries. Therefore, it was recommended that in cases of collaboration between developed and developing countries laboratories in the field of biotechnology and field tests should be done in developing countries, the guidelines in handling the organism of that of the developed countries should prevail. Commission on Plant Genetic Resources of FAO, in its Fourth Session (1991), devoted its discussion on the development of legal and regulatory matters, in which the handling and release of genetically modified organisms and Intellectual property rights over plant genetic resources become the focus.

# Lessons Learned

In reviewing the development of biotechnology in Asia, the following points are worth noting:

## National Policy on Biotechnology

Most countries in Asia put biotechnology as one of the top priorities in their research and development agenda. However, in putting resources countries differ in their commitment.

## Institutional Arrangements

Research and development in biotechnology are carried out in various universities, research institutes and to some extent in industries. Several countries has centralized policy and in so doing more or less coordinated efforts are in place. In others, each research unit within a country has its own interest and that is not necessarily related to solving the domestic problems. Such fragmentation prevents the pooling of the scarce resources.

## Resources

Biological resources, plant genetic resources in particular, are the raw materials for biotechnology precesses. Let alone, these resources will not mean much to a country. They require the skilled man power and the appropriate technologies to their potentials. Included in those technology resources are the delivery system. Both types of resources are rather limited in the developing world of Asia. The trained man power are often loaded with multiduties leaving them with no time to do research, which is important for the basis of technology adoption, adaptation and development.

## Programmes

Research activities on biotechnology cover a wide range of topics and are done at various levels of sophistication. In developing region of Asia these activities have lead to the mastering of new techniques in biotechnology. Quite often, however, the capability scattered in different research units. Further question is necessary if development will get benefit from biotechnology: what will we do with the techniques? The potential application of biotechnology in industry, medical care and agriculture have been shown. In either of the three areas mentioned, human resources and financial resources are limited in developing countries of Asia. Because of this limitation, priority should be set up if biotechnology is expected to contribute to development. Within the research program then not only the technical matters should be the concern, but also the economic return and the social implication should be addressed.

# Development Assistance

In building the national capability for biotechnology, quite often the developing countries of Asia received supports from outside. Sometimes supports in the form of soft loan were exercised. Without a clear focus on the program, it is difficult to measure the effectiveness of the foreign aids.

Developing countries in general lack scientific infrastructure and financial resources to carry out new biotechnology activities. There are ways to develop the national capability, among others through:

## The United Nations System

Several agencies under the UN system are in the position to assist their members in developing human resources for biotechnology or closely related subject:

a. United Nations Industrial Development Organization (UNIDO) has launched International Center for Genetic Engineering and Biotechnology (ICGEB) in 1980 with the headquarters in Italy and India. The main purpose of the establishment was to set up a center of excellence for biotechnology research for developing countries' needs.

b. Food and Agriculture Organization (FAO) is developing a sound proposal for Asia-Pacific networking in biotechnology. If accepted by the United Nations Development Program (UNDP) then national capability in agricultural biotechnology will be developed through regional networking using matured technology as the driving force.

c. United Nations Environment Programmes (UNEP). A convention on biotechnology is expected to be signed by the number countries of UNEP in Brazil in June 1992. If this convention is materialized, developing countries will be in position to exchanging their biological resources with technology, including biotechnology. Unfortunately, however, the negotiation went slow because there was a fundamental difference in perception between the developed and the developing countries concerning the transfer of biotechnology and its related issues.

d. United Nations Education, Science and Culture Organization (UNESCO) Since its inception, UNESCO has assisted its member countries, specifically the developing countries with training and education in sciences. One strong component of its programmes is in the field of biology, microbiology in particular. With the advancement of microbiology into molecular and cellular biology, UNESCO is confronting with new challenges to supporting the new area of biology.

## The Consultative Group of Agricultural System

Maintenance research is required to sustain what have been achieved in grain production through green revolution. Under the joint sponsorship of FAO, UNDP, and IBRD, a Consultative Group of International Agriculture was established (Swaminathan, 1991). Within this CG System, now there are 17 research institutes in which biotechnology in one way or another is applied. The involvement of private industries in developing biotechnology for food production and their partnership with the institutes within the CG System have created worry among the non government organization (Hobbelink, 1991). On the other hand, the developing countries are cooperating with the IARCs long before the issue of biotechnology and the patenting problems. Through IARCs crop improvement with the associated activities are tackled with biotechnology where appropriate by the developing countries. Such cooperation develops capability in Asian countries as well.

## Bilateral Assistance

New techniques in biotechnology deal mainly with cellular and molecular biology. Many developing countries in Asia lack of molecular biologists to enable them to tap the application of biotechnology, let alone by develop it for certain purposes. Recent technical assistance granted by developed countries to developing countries covers among others biotechnology. Government to government arrangement caters individual needs of each country. US-AID, for example, organized a panel of experts to set up program which US-AID might fund (NRC, 1991). The same hold true for United Kingdom, Japan, the Netherlands, Australia, etc., through their appropriate agency include biotechnology in their technical assistance. Both degree and non degree training enhance the human resources capability. Coupled with this program sometimes the needed equipments are included.

## Bilateral Sector

Large international foundations, such as that of Rockefeller, show interest in the development of biotechnology for the developing countries. A world-wide networking on rice biotechnology is sponsored by the Rockefeller Foundation. Meanwhile, transnational corporations have strong programmes on biotechnology. Developing countries may take advantage of it. However, concerns have been expressed that not only the biosafety should be taken into consideration, but also the control of the new technology (*Development Dialogue*, 1988). It is clear that cooperation with the private sector is desired, however, cautions should be taken.

## Toward More Sustainable Efforts

Information technologies bring the countries in the world closer and closer. What happens in Latin America or Europe in a matter of seconds has been widely known to Asia. Easier and faster transportation between countries enables man to travel from one corner of the world to the others. The era of globalization affects every country and in consequent, it requires a more understanding between nations both developed and developing. Biotechnology development is only one of the many global issues that the world community are confronted with. The beauty of biotechnology is that it is closely related to other issues, such as biodiversity conservation, food products, health, or pollution. Though biotechnology is generally understood to be of politically and target wise neutral, yet many are concerned with whether or not the developing countries are in position to go along with the developed countries in its applications. Realizing that the world population is increasing every year despite of the success of family planning program and the fact that the misery of its effects can no longer be confined to a given territory, it is logical that biotechnology application should be aimed at a wider target than the monetary term. Private industries are no doubt driven by profit motivation and looking for a big market. Without a big market, they cannot possibly pay the cost for effective biotechnology research and development. The question becomes, how can the public sector benefit from this situation? Biotechnology needs raw materials to be processed into new products with much higher value. The raw materials are found naturally in many developing countries. Unfortunately, these resources are at stake of erosion, because of the fact that populations are concentrated in these countries. What more, the number of poor families are higher in these countries compared to those of the developed regions. Without a sustainable effort to conserving the wealth, before too long the raw materials for biotechnology will be depleted. This situation needs considerable cooperation between countries which are rich in biological resources but poor in technological resources and the countries which are rich in technological resources but poor in biological Resources. Sustainable efforts are required if long term effects are expected.

Competitions between countries do always exist. Secrecy is the trait of biotechnology application. They have got to be balance between the urgency to compete and the need to cooperate if biotechnology is to be useful for mankind. Without a long term commitment of countries to work together, the problems we face to day will be a disaster to all of us. This is the issue confronting the countries in Asia where 50% of the world population live.

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# Biotechnology for Developing Countries: The Mexican Case

*José Luis Solleiro*

*Centre for Technological Innovation, Autonomous National University of Mexico*

## Abstract

*In the opinion of many specialists, biotechnologies have in general kept their promise with regard both to results expected from research and to their potential applications over the last ten years, in particular in the industrialized countries. This decade will witness the marketing of an increasing number of biotechnology-derived products, which will co-exist with conventional products or will replace them.*

*The control of innovation in biotechnology is increasingly falling in hands of large multinational firms and consortia. Developing countries have begun to pay attention to the positive as well as the negative impacts of biotechnology in all areas of development and some of them are supporting biotechnological research. Nevertheless most of these countries have followed an imitative pattern to select their research programs and, as a consequence of this, they have found a lot of obstacles to generate innovations capable to reach the commercialization stage. This reflects a lack of sound methodologies for setting priorities of development which are essential in order to allocate effectively limited human and financial resources, to avoid a disarticulation of research from its practical application, concentrate on realistic opportunities and reduce duplication of effort.*

*This paper analyzes past experiences in the priority setting process related to biotechnological research as well as in the development of biotechnology-based companies in Mexico. Doing so it is attempted to identify and describe the main factors influencing the possibility of diffusion of biotechnologies in the country.*

*Finally, the paper presents a set of recommendations to overcome barriers, limitations and difficulties for the development and application of biotechnological innovations, including some relating the design of a suitable policy framework for the promotion of biotechnology. This policy framework derives from the priority areas which have been found by recent studies.*

# Introduction

In the opinion of many experts, biotechnology is viewed as a possible technical and scientific revolution developing towards the end of the present century, bearing in mind the expectations resulting from research and its applications, particularly in the industrialized countries.

During the present decade we shall witness the marketing of an ever increasing number of biotechnology derived products. These will either coexist side by side with traditional products, or will end up displacing them (Sasson and Costarini, 1991).

Increasing interest in biotechnology has given rise to a large number of definitions. For our purposes in this document, by biotechnology is meant the "overall number of technological innovations which are based on the use of microorganisms and microbiological processes with which to obtain goods and services and the development of scientific research activities" (Bull et al. 1982).

The range of applications created by the new biotechnology includes new possibilities for its use in the most diverse fields (from farming and health up to and including mining), all of which has awaken remarkable economic expectations, some of them excessively optimistic.

It is very obvious that biotechnology is a phenomenon that in all likelihood will require the introduction of structural changes in our society. For this reason, the different elements impacting on this technical change must analyze their own roles, while avoiding falling into a participatory action full of enthusiasm but lacking in talent and prudence. It is, therefore, necessary to ponder many economic, commercial, technical, social, ecological and political factors in order to make appropriate decisions.

Taking the case of Mexico as an example, this work analyzes some of the factors that must be taken into account when defining biotechnological policies in the developing countries. (Examples of current work are presented in the case studies at the end of this paper.)

# Biotechnology for the Developing Countries

There is no doubt that biotechnological sciences offer a large number of flexible techniques which can be applied to many areas, although it is also true that these techniques have not emerged in a vacuum, in addition to their not being inert as regards their socio-economic and political consequences.

During the last few years, an optimistic literature has appeared according to which biotechnology is seen as the panacea that will solve the problems of the developing countries. There are also authors who attest precisely to the contrary. At the outset, it can be said that the best position from which to make decisions in this field in the developing countries will be one that excludes extreme positions.

To this end, the possible positive or negative effects of biotechnology upon the following aspects must be borne in mind (Sasson and Costarini, 1991):

- Increase in farming productivity and in food production, through the direct use of plant biotechnology, complementing conventional technologies.

- Nutrition, through improvement in farming and agro-industrial production, and techniques of fermentation in food processing.

- A better integration of food production with the production and consumption of bioenergy at the household and small settlement levels.

- Improvement in livestock production and in the health of domestic animals.

- Correctness in diagnosis and prevention of diseases, as well as upon public health.

- Commercial exchange patterns between developing and industrialized countries, as a result of differences in dynamics in the introduction of productivity improvements both in farming and agro-industrial activities; also, of the marketing of new biological products which have a tendency to displace raw materials and products from the developing countries, depriving them of an important source of revenue.

- Income and employment.

- The possible expansion of cash crops at the expense of food producing crops.

- Strengthening of large farming operations, with the subsequent displacement of small farmers.

- Possible reduction in genetic diversity as a result of the broad distribution of new crops.

- The increasing privatization of the results of research, to which the developing countries do not have easy access, being forced to paying fees for the use of seeds and plant varieties developed by the industrialized countries.

We can see that the preceding factors can have far reaching consequences. In addition, we expect that the adoption of new biotechnologies by the developing economies will be concentrated in the sectors of greatest economic development potential, will increase internal social differences and concentration of ownership of farmland, and bring greater poverty to small producers and hired manpower. This will also bring about an acceleration of migrations from rural areas, while increasing the cost of medicines and other health products, etc. (Hidalgo y Monge, 1989).

Faced with this perspective, the only way to confront the above risks while taking advantage of existing opportunities, will be by having a greater control over biotechnology in the developing countries, which will depend to a great extent on the level of scientific and technological knowledge already attained in this area.

The developing countries must not believe that they will be able to go "shopping" to the technology supermarkets of the industrialized countries (Deo, 1991). On the contrary, given the barriers erected against the transfer of biotechnology, third world countries will have to concern themselves with maximizing their natural, scientific and technological resources with which to define problems and seek solutions for the benefit of broader sectors of their respective societies.

# Erection of Barriers and Control of Biotechnological Innovation

As previously mentioned, the expectations created by biotechnology have given rise to a race for control of the resulting innovations and new markets (Correa, 1991). This control is increasingly being exercised by large corporations and multinational consortia.

At present, there are three large categories of institutions carrying out research and development (R&D) in the biotechnology field. The first encompasses the universities and not-for-profit R&D centres that carry out both basic and applied research. The close connections established between universities and large and small biotechnology companies are very numerous. (See Table 1, where the biomedical R&D is illustrated).

The second category of institutions involved in biotechnological R&D projects are venture capital companies and R&D companies; the latter are usually small, although somehow related to large multinational corporations. The third category embraces the transnational corporations themselves.

Thus we see that the multinational corporations have undertaken a strategy enabling them to maintain all their options open, ensuring their preferential access to the results of research that offer some marketing potential, transferring the development risks to third parties while trying to maintain monopolistic positions in the world market (Dembo et al. 1988).

In this manner, European, American and Japanese companies, frequently interfacing through strategic alliances, compete among themselves in the open market. However, success in this market is not an easy matter, because several entry barriers must be overcome.

The first difficulty lies in that biotechnology requires for its development solid interdisciplinary scientific teams in such areas as molecular genetics, immunology, protein chemistry, biophysics, industrial microbiology and computer sciences (Correa, 1991). However, the greatest problems are not found at the scientific level: the main bottleneck, in the majority of the countries, arises as a result of the low engineering level in product recovery processes, this being the basic element for the industrial application of these techniques (Sercovich and Leopold, 1991).

The resources necessary to undertake biotechnology R&D may also be a serious obstacle towards its inception. Also, resource requirements go beyond the exclusive scope of the research activity. Different type of inputs are required; in fact, the greater the scale of the biotechnological operations to be undertaken, the greater the relevance of the availability of such material resources as equipment, process control instruments, standardized raw materials, etc.

In addition, we must also bear in mind that certain types of inputs are highly specialized and are not massively available (for example, superproducing fermentation strains). In response to this fact, entirely new companies are appearing as specialists in the supply of special inputs for biotechnology companies.

Unfortunately, technological capacity in itself does not guarantee a successful commercial and economic biotechnology operations. Distribution and marketing of biotechnology products may encounter barriers far more complicated than those posed by reasons of a technical nature. On account of this fact, many starting-up companies have had no other alternative than to grant marketing rights of their products to other well established companies (Correa, 1991).

Therefore, from all that has been said it is obvious that access by developing countries to biotechnologies, as well as their capacity to adapt them, are fairly limited.

To really benefit from some of the potential applications of the biotechnology field, developing countries need to confront the problem of technological dissemination and define policies and practices that will make its use possible.

Table 1. Cooperation in Biomedicine Between Universities and the Corporate Sector.

| Pharmaceutical Company | Institution | Field | $ Volume (million) |
|---|---|---|---|
| Merieux Inst. | Univ. of Toronto | Vaccines | 15 |
| Hoechst | M G H | Molec. Biology | 78 |
| Monsanto | Washington Univ. | Biomedical Res. | 100 |
| Upjohn | Univ. of London | Central Nervous System | 5 |
| Roche | Harvard Med. Sch. | Immunology | 10 |
| Smith Kline Beecham | Oxford University | Neurobiology | 10 |
| Shieseido | M G H | Dermatology | 85 |
| Eisai | Univ. of London | Central Nervous System | 100 |
| N o v a | Johns Hopkins | Cancer | 7 |
| Ciba-Geigy | Cal. Univ. S.D. | Arthritis | 28 |

Source: Haber, E. (1991) Biological Concepts as the Basis for Pharmaceutical Development. Association of University Technology Managers; San Francisco (February).

This specifically means that efforts must be made to develop local capacities enabling to select, acquire, develop and implement biotechnological products and processes in those sectors where the country has clear comparative advantages upon others. This requires that we be selective and that we start from a very honest analysis of strengths and weaknesses, in order that we may be able to realistically identify these comparative advantages.

## Biotechnology in Mexico: A Brief Diagnosis

In Mexico, biotechnology is represented by a mixture of industrial and promotional R&D activities which are carried out at different levels of technological and scientific complexity. To asses their development and status in the country, and to estimate their possibilities and potential, it is necessary to define and delineate this sector, using the available information (Quintero, and Gonzalez, 1989).

Mexico incorporated the technology field into its industrial, technological and scientific plans during the 80's. Until now, all actions taken in teaching, research, technological development and industrialization in this field have been interconnected. Lacking an explicit biotechnology promotion policy, seems to be a consequence of this, although at the discourse level it has already been considered as a priority area.

Thus, the first generation of the biotechnology industry is the most important category, in terms of market size. Its main products are fermented beverages, milk products, bread yeasts, alcohol and edible mushrooms. Companies involved are very much oriented toward the domestic market, their R&D activities being thus very limited.

With regard to second generation biotechnologies, several companies produce antibiotics, aminoacids, organic acids and biofertilizers. A large share of the biotechnology employed by these companies is foreign. In this field, there are some groups of R&D, concentrated in universities and public research centres, that very seldom have interfaced with commercial enterprises, without having marketed any commercial product.

With respect to biotechnologies of the third generation, manipulation of microorganisms has been restricted to universities and public R&D centres. We have some high quality research groups, but these are not closely connected with the productive sector, by the mere fact that companies working in these technologies in Mexico are exceptionally rare.

A recent diagnosis carried out by Erossa et al (1989), includes a qualitative assessment of the biotechnology industry in Mexico. The main conclusions of this study are:

a) The food industry shows signs of disarticulation in the productive chain giving rise to scarcities; insufficient and occasionally defective infrastructure in warehousing, supply and transportation cause losses in the range of 30% in fruit and vegetables and 50% in fish and seafood products; consumption and industrial concentration; low competitiveness caused by technological obsolescence of machinery and equipment, as well as inadequate economies of scale; all this is compounded by an insufficient technological development that exacerbates our dependency from abroad.

b) With regard to the pharmaceutical industry its integration is very rare, in the majority of cases being carried out during the last stages of the productive chain, and being dependent upon the importation of the intermediary products the country requires for the manufacture of its pharmaceutical products, as well as of the corresponding basic technologies.

c) In the case of the biotechnological industries, most of them are under the control of foreign investors. The national industry performs little research: It does not adapt or improve imported biotechnologies, depending again upon raw materials, equipment and qualified personnel of foreign origin.

d) In addition and with regard to the agricultural industries, a study carried by Solleiro et al (1991) shows that their level of global competitiveness is lower than that of other countries with similar level of development as Mexico's, with the presence of many companies very different among themselves as regards their marketing power, productivity and technological efficiency.

e) With regard to livestock, national experts are of the opinion that the new biotechnology is still far from being applied to the Mexican livestock sector. For the time being, its use is confined to the country's largest breeders. The infrastructure for industrial and domestic research does not have economic capacity to invest in costly and long term studies as required by this type of activities (Solórzano, 1989).

To the preceding conclusions it should be added that biotechnological markets have not been sufficiently assessed as no system exists to monitor and analyze the international technical and market information available in the biotechnology field.

We can advance the conclusion that short of a substantial increment in the technological capacity of the industries of the sector, any policy initiative shall be in danger of being an exercise in rhetorics.

## Research and Human Resources in Biotechnology

There is no doubt that biotechnology R&D, although circumscribed within the general scientific and technological development of the country, it presents the characteristic of being a fundamental element, especially because the main applications of biotechnology are yet to arrive.

A study of the biotechnological status of the Latin American countries has been recently carried out (Jaffe, 1991). The study reported that the main problems confronting the region in the field of R&D are the following:

- Insufficient R&D funding
- Lack of priorities
- Lack of human resources
- Deficient infrastructure and equipment
- Importation difficulties.

In the case of Mexico, the study of Ana Irene Solórzano (1989) explains that research activities are disarticulated. There is no a biotechnology domestic plan for which priority areas of research have been defined. Interinstitutional relationships are very limited, thus causing a duplication of efforts.

Even though it has been asserted that biotechnology is an essential area, the number of R&D projects in biotechnology or connected with it in 1987 were only 1.4% of the total number of R&D projects being carried out in the country.

Basic research is not very innovating; almost invariably it follows a pattern imitating foreign studies, and most of the time it does not respond to domestic socio-economic interests and requirements.

Applied research is chiefly oriented towards the health, environment and the food farming sectors. This type of research is oriented towards two extremes. On the one hand, there is a good number of projects looking for the development or adaptation of "simple processes", seeking to create an impact through reductions in production costs, and not through the transformation of the productive process or the creation or development of new products.

This is the case of projects aimed at the farming and livestock sectors -which together have a greater specific weight than the industrial sector in financing biotechnological R&D - in which the objectives of research are not to increase efficiency or speed in crop propagation, production of virus free plants, production of new vegetal varieties or animals with better characteristics of reproductivity and resistance to disease or to environmental adversity, as these are the basic ways by which it is expected biotechnology will impact upon the livestock sector (Soleiro et al. 1991).

On the other hand, there are research groups that seek applications for the new biotechnology, using in the process well equipped laboratories generally located in university settings. Within these groups the imitation pattern is repeated once again, as many of them seek to develop products which, although they are offshoots of new technologies, they are already on the market under the control of very powerful corporations. It is obvious that given the existing entry barriers, the industrial viability of these projects ought to be questioned.

To the problems previously mentioned, we must add that a great part of the process generated by research centres is arrested on account of their low profitability, or simply because it is not possible to demonstrate their economic viability (Casas, 1987). Besides, in spite of the applied orientation and the commercial motivation of the projects, our short experience in large scale production problems and in the marketing of final products, does not allow for the application of results. (Eastmond, 1987).

This last point reflects the fact that biotechnological research projects in our country lack a corporate orientation, thus reducing radically their success probabilities, in as much as the technology user will always be a corporation.

For its part, the domestic productive sector has not assumed an adequate participation in biotechnological development, leaving the initiative in the hands of the universities and public research centres, or even in the hands of transnational corporations.

If we are not able to change this situation, it is very likely that any initiative will fail.

Finally, another characteristic of biotechnological development during the last few years is its strong concentration in just few States, particularly in Mexico City and in very few research centres, adding further difficulties to the dissemination of results.

As far as human resources and training are concerned, there is a high consensus with regard to the fact that there is a shortage of qualified personnel in the biotechnology field.

According to Erossa, in 1989 there were 848 researchers working in biotechnology; about 650 belonged to institutions of higher learning, 20% to public research centres and the rest to the productive sector. Sixty percent of these researchers has undertaken postgraduate work.

The post-graduate national system has the capacity to train about 65 biotechnologists per year. Besides, another 4 or 6 can be trained abroad. Although this supply is rather low, it exceeds the requirements of the country's biotechnology industry, which until recently has only required personnel with medium to high qualifications. Under these conditions, the employment possibilities are limited to teaching and research in public institutions, where salaries are so low that detract from undertaking training in this field. We have proof of this in the fact that in 1989 all post-graduate students in biotechnology, bioengineering and bioelectronics represented only 0.2% of all post-graduate enrolment (Solórzano 1989).

In addition, this structural problem is made more acute by the fact that no program incorporates guidelines towards the design of equipment and industrial or laboratory instruments, and this causes the expectations for industrial process development to be low.

# Regulations and Intellectual Property

Another point of consensus amongst experts in the establishment of biotechnological policies is that which refers to the appropriate legal and regulatory framework (National Biotechnology Advisory Committee, 1991) towards establishing a national strategy.

On the one hand, complying with regulatory requirements in biotechnology is a critical factor affecting the time and cost necessary to market a product. In general terms, the need for regulations ensuring the health and safety of workers, consumers and the environment is amply recognized.

Emphasis is also put on the fact that the system must, while building confidence, possess economic rationality and be internationally compatible. This system must permit long term development planning and marketing of new products, while being flexible enough to adapt itself to the characteristics of each new development. The jurisdiction of each regulation must also be clarified in order to prevent duplication, focusing the whole process on principles of risk evaluation.

Mexico does not as yet have a regulatory framework that includes all the previous characteristics. The General Law of Ecological Balance and Protection of the Environment (Ley General de Equilibrio Ecológico y de la Protección del Ambiente) that was enacted on January 1988, stipulates some regulations for the prevention and control of contaminants and for the rational use of water.

There is also a Health General Law (Ley General de Salud) which includes regulations for the research in the health field, and a Law concerning Production, Certification and Marketing of Seeds (enacted in 1982), as well as a Law for Phytosanitary Protection.

Nevertheless, an all encompassing regulatory body does not exist, and there is a great lack of knowledge on the importance of its proper application, and this either deprives technological development projects of the required momentum, or places our country in such liberal position that Mexico may be used as "test territory".

With regard to intellectual property, it is worth noting that obtaining patent rights for biotechnological inventions has become a fundamental objective of companies seeking the commercialization of biotechnology. It is obvious that the main beneficiaries of the patenting process are the large multinational corporations. These patent their products or processes in a given country, not with the primary objective of transferring technology, but in order to export it from their country of origin, thus eliminating all possibility of competition.

In spite of this, in June 1991, the Congress approved a new Law for the Development and Protection of Industrial Property, which inaugurated the patentability of biotechnological inventions in Mexico. Thus, new plant varieties, microorganisms, biotechnological products and processes can also be protected.

The enactment of said Law was preceded by great pressures by the United States. In fact, almost nine months after its publication in the Official Gazette, we have not been able to know as yet the details of the pertinent regulations outlining how new patent rights may be applied for. This is just a reflection of the lack of preparation in the country for such an important step as that taken by Mexico.

# Mexican Experience in Establishing Biotechnology Policies and Priorities

It has already been said that biotechnology began to receive priority attention in Mexico at the beginning of the 80's.

In fact, towards the end of 1982 biotechnology in Mexico received political support by being included as a research priority area in the 1983-1988 National Development Plan; subsequently, in the 1984 Annual Operating Program of the National Council of Science and Technology (CONACYT), three of its 28 indicative programs were related to biotechnology.

In 1984, Banamex's Industrial Co-investment Program included biotechnology in its strategic plan. Also in 1984, in order to increase the contribution of technological, administrative and financial resources from abroad and to build Mexican companies with participation of foreign capital, foreign investment guidelines were issued.

Said guidelines sought to channel foreign investment towards selected industrial activities, particularly complex and of high technological level, which included biotechnology.

Since 1983 several attempts have been made to develop a Biotechnology National Plan defining research and development priorities in this field. Although this idea has been examined at the scientific, political and industrial levels, efforts made have not been successful, and for practical purposes no changes have taken place in the national biotechnology development (Solórzano, 1989)

The 1989-1994 development plan (PLANADE), envisages the promotion of biotechnological development and the consolidation of progresses made in the country. PLANADE's basic structure includes directly or indirectly those economic activities upon which biotechnology may have determinant effects.

One of the actions proposed by PLANADE to bring about economic recovery, price stabilization and improvement in the living standards of the population is the economic and technological modernization of the primary activities sector, and of the industrial and service sectors.

PLANADE also proposes to support the export of non-petroleum products, foreign investment, technological transfer, international cooperation and protection of the environment. Of the medium-term programs defined in PLANADE under the items of health, nutrition, supply and hygiene, protection of the environment, water conservation, energy modernization, updating and modernizing primary activities and mining, etc., biotechnology is considered as a priority technology. Nevertheless, an explicit program promoting biotechnology continues undefined.

In spite of not having this explicit policy, research projects are being carried out in Mexico which involve a broad range of applications. This is the result of several decades of efforts made in human resources training and in the development of biotechnology, but it is also a consequence of the lack of well defined priorities that would have avoided dispersal of research efforts.

About 10 studies on perspectives for determining research priorities in biotechnology have been carried out in Mexico (see Table 2).

This experience, together with that of Latin America, shows that most of these studies have been commissioned by groups that assign economic resources for development or dissemination of biotechnology, and clearly illustrates the fact that developers and users of the research have not shown great interest in finding said priorities, or even opportunity areas.

Some of the most important aspects derived from the Mexican experience are: Difficulties in defining and classifying biotechnology; problems in having a reliable information source on the biotechnology situation in the country; lack of knowledge on the subject and its importance among the various executive levels; application of inadequate methodologies; lack of mechanisms to use the results of the studies; reduced number of experts; and the lack of connection between the conclusions and the decision makers so as to promote a definite policy.

Even though important efforts have been made in spite of this situation, it has not been possible to articulate policies starting from priorities outlined, as these have not been adequately defined or have been concentrated in generating recommendations that were overly general, therefore vague.

If these difficulties are not overcome, it is very likely that Mexico may be compelled to follow internationally recognized research lines, and even this at a minor scale. Should the same pattern continue of industrial sector participation and financial support, it is most probable that our country may be prevented from using its own biotechnology in industry as well as in agriculture both in the short and medium term.

Table 2. Mexico. Experience in Determining Biotechnology Applications (Prepared as per data from R. Quintero, (1991)).

| Year/ Duration | Study | Sponsor and Executor | Objective | Methodology | Results | Limitations |
|---|---|---|---|---|---|---|
| 1981/ 18 months | Analysis and expectations of biotechnology in Mexico | Programs and Budget Section. Private consulting firm. | To establish a national biotechnology strategy | A group of five experts prepared documents on their areas of expertise. Bibliographic Rev. | Inventory of biotechnological activities. Classification of biotechnology in four groups. A book on it. | Vague objectives. Low budget. Lack of methodology. Lack of information. |
| 1984/12 months | Biotechnology in Mexico. Opportunity evaluation. | CONACYT. Barros Sierra Foundation. (Centre for Prospective Studies) | Identification of areas and R&D priority projects to be financed by CONACYT. | Consulting group prepared documents on eight application areas. Evaluation of documents by scientist groups, corporation execs. and public foundations. Bibliographic Rev. | Examination of 107 projects. Ident. three application areas (Health, agriculture, chemical products). Ident. limiting factors: financing, patents, and University-Industry linkage. Participation of 150 people in meetings. Book on...(sic) | There were no mechanisms to implement results. Limited budget. Limited participation of experts in new areas. Deficient analysis and evaluation of available documents. |
| 1984/6 months | Biotech. perspective and its implications for the national productive sector. | BANAMEX. Barros Sierra Foundation | Identification and classification of nationally developed biotechnological projects, for their eventual industrialization and marketing. | Examine state-of-the-art national and international. Visits and interviews with national and international companies (U.S. and Canada). Classification of 30 projects as per 10 economic criteria. (Classif. 1-10). | 10 high potential projects selected for national development. New vision on biotech marketing and internatl competition. Compiling info on industrial biotech in...(sic) | Difficult to obtain economi information on biotech. Expert little experience in selecting potential industrial products. Well defined method but difficult to apply. |
| 1986/6 months | Biotech company in government sector | SEMIP Project Evaluation Centre | Proposal to create a new biotech state company to carry out mainly State projects (PEMEX, SSA, FERTIMEX, PIPSA, CONASUPO, etc.) | Examination of present and future applications in State controlled companies. Individual consultations with national and international experts. | Design of a multi-purpose biotech company. Identification of a lack of a technological development policy in the State sector. | Little or no participation of State controlled companies in study. Lack of tech and commercial inf in State companies. Limited knowledge of biotechnology and its applications. |

TABLE 2. (Cont'd).

| | | | | | | |
|---|---|---|---|---|---|---|
| 1988/6 months | Strategic study for the CYDSA group in the biotech field. | CYDSA (private group) Private consulting firm. | Identification of a group of biotech projects and their priorities according to the interests of the company. | Natl and internatl State-of-the-art examination of biotech. Analysis of biotech by sector. Select projects and products using criteria (type of client, raw material producers, interest in same sectors). Classify projects/products using the potential methods with chemical industry standards (qualif. 1-4). | Selection of 12 projects. The first of these gave rise to a new company within the industrial group. At a corporate level, a search for opportunities for its companies was initiated. | Little knowledge of biotech within the company group. Conservative attitude. Search for business with results at short and medium term. |
| 1991/6 months | Priorities in biotech for international technical cooperation | S R E UNAM Biotechnology Institute | Establishment of a list of biotech priorities for their promotion by SRE, aiming at international technical cooperation (Scholarships, exchange of academics, joint projects, information exchange). | 8 experts prepare documents and propose priorities in four application areas. 10-15 experts examine proposed priorities (decide by consensus). Exam of the country's S&T state-of-the-art as it applies to biotech | Lists priorities research, training, cooperation products. Ident of outside groups with which advisable to establish cooperative relationships. Ident national capacity that can be offered abroad. | Change in relative importance of project for SRE. Difficult to find group to perform the study. Deficient/ outdated info on status of biotech in country. |

It is for this reason that priority determination must be considered as a dynamic and participatory process, valid within a given time frame (as a function of available elements when priorities are defined), which must made periodically (in keeping with the dynamics of the sector, area or field under consideration).

This tool must not be considered as a universally applicable process, as it will vary as a function of the values, preferences, needs, capacities, resources and opportunities of the institutions for whom the work is performed (national, sectorial and institutional public or private). Besides, determination of priorities is rarely ever placed at the first level of policy definition.

It will also be essential that the priorities determination process be integrated with those from whom the demand will originate, namely the productive sector.

Methodologies based on the opinion of experts indicate that it is important to establish the expert's profile. This must not be "married to his discipline", as the process under discussion must be as open as possible in order to identify the clearest opportunities and to present competitive technological packages to the international market.

# Basic Aspects Towards Establishing a Biotechnology Policy

In view of the positive and negative effects biotechnology can have for a country such as Mexico, important efforts must be made to enable the country to develop and consolidate its bioindustrialization; "this implies creating conditions favouring the promotion of a process to accumulate different capacities that will allow to generate, acquire and use biotechnology" (Avalos, 1990). We must underscore that it is not only a question of increasing investments in R&D in order to have greater scientific capacity. It is also important to develop abilities to adopt and assimilate biotechnologies developed abroad. Therefore, in addition to the scientific capacity and the quality of the educational system, it is fundamental to have a monitoring system of the state-of-the art of biotechnology, of its suppliers and of the evolution of the international market in this field.

Summing up, in the biotechnology field we should seek the development of an innovation national system; this concept designates the existence of organizational devices and functional mechanisms to achieve a greater linkage between science, technology and the market, thereby fostering processes for generation, dissemination and use of innovations. "In other words, it refers to an institutional organization framework allowing to link different capacities (information, abilities, equipment, financial resources, etc.) located in different institutions (public laboratories, university research centres, consumer goods companies, machinery manufacturers, engineering firms, etc.) so that to facilitate innovation processes." (Avalos, 1990).

To develop a policy that articulate this Innovation System, the State must manage agreements of a different nature in order to integrate resources around common objectives, giving cohesiveness and complementariness to different policies having a bearing on biotechnology innovation. These policies are:

* Scientific policy
* Technological policy
* Industrial policy
* Financial policy
* Export policy
* Regional integration policy
* Regulatory policy

With this framework in mind, following are some basic recommendations towards the establishment of a biotechnology policy for a country such as Mexico.[1]

It is not our intention to present a detailed plan here, as this could only be developed starting from a rational analytical process of the strengths, weaknesses, opportunities and challenges and from decisions based on the participation of the productive, academic and government sectors.

First of all, it should be noted that to formulate a policy one must start off from certain basic premises (Arroyo and Waissbluth, 1988):

1) The country must have a strong scientific establishment in place, able to develop a technology of its own or to negotiate or adapt that originating in other countries, taking into account all economic, technical, social and ecological aspects having to do with biotechnology.

2) Creating a solid technological and scientific infrastructure is an indispensable requirement to confront international competition. This requires a significant increase in R&D expenditures. But this effort must not be an exclusive responsibility of governments. The public sector must make a significantly greater contribution (about 50% of the total expense).

3) In modern biotechnology, the most important production factor is qualified human resources. Without a definite training policy, both with regard to basic sciences as well in practical matters (such as handling laboratory techniques and pilot plants), any mechanism that may be established will have, from its inception, a great risk of failure.

4) Scarcity of human resources and capital are factors that should be administered in a rational way, being therefore indispensable that biotechnological development priorities be established. Trying to cope with all fields and all possible applications would entail dispersion of efforts that would tend to neutralize them.

5) It is also indispensable that biotechnological policies be linked with macroeconomic policies, and with those impacting on other sectors, in order to achieve consistency and compatibility (Redgrave, 1991).

[1]This section is based on the article by Solleiro and Arriaga entitled "Biotechnology Patents, challenges and options for Latin America"; Revista de Comercio Exterior, 40-12.

6) The policy definition process should agree with certain minimum regulations imposing a certain order.

Thus, the general sequence should be:

Phase 1. Establishing long term strategic objectives, and definition of priorities.

Phase 2. Definition of opportunities and requirements for the different regions and/or sectors.

Phase 3. Selection or design of policy instruments pertaining to each priority in the biotechnology field.

Phase 4. Definition of roles, action plans and agreement among different participants.

Once all these basic premises have been taken into account, the country ought to define a biotechnology development plan as a national priority. The identification of options and specific priorities of said national plan must be a product of a detailed analysis of strengths and weaknesses, as well as opportunities and challenges.

Upon completion of the analysis of strengths and weaknesses of the present biotechnology development, as well as of challenges and opportunities for the future, and upon identification of areas to be considered as having priority in keeping with this diagnosis, it is advisable to identify all government and institutional policy instruments required to push said priorities forward.

The purpose of this work is not to present an in depth study of promotion instruments, although those mentioned hereafter would constitute a suitable structure:

## Financing

A special biotechnology fund must be created to finance the development of infrastructure, basic research, contribution of venture capital (for technological development and investment), scholarship programs and exchanges with other Latin American countries. The assignment of funds must correspond to priority areas.

## Training of Human Resources

There is a widespread agreement that modern biotechnology requires the development and application of knowledge of biochemistry, microbiology, molecular biology and genetics. As a result, any biotechnology program will have to assign a high priority to the strengthening of higher learning units responsible for training human resources in these areas. This requires that teaching programs include the latest developments, that the academic infrastructure be considerably improved, that new experimentation facilities be created for molecular biotechnology and genetics (subjects on which the new technology is based), that teaching programs of biological sciences be adopted based on the interdisciplinary concept, and that intensive use of computational equipment for teaching and research be promoted.

## Information

An essential instrument to improve access by all countries to the new technologies and to strengthen their negotiating position is to promote access to technical information. A network of libraries and technical documentation centres must be created incorporating the latest advances for retrieval, storage and dissemination of the information contained. The costs of this infrastructure should be considered as an investment, having a very favourable cost/benefit ratio. Limiting access to information would reduce the chances of making correct biotechnological decisions.

## Communication and Interfacing with the Developed Countries

Even though privatization of knowledge is an increasing phenomenon, the door is not yet closed for the developing countries. Having recourse to the different international cooperation mechanisms should be an immediate priority. And within these mechanisms, preference should perhaps be given to sending students on scholarships to first class university and research centres.

Advantage should be taken of the support opportunities offered by international centres and institutions (such as the International Genetics Engineering Centre), where access to knowledge should be primarily sought.

## Support to Enterprise Development

It has been demonstrated that an efficient mechanism for biotechnology dissemination is through the creation of so-called knowledge enterprises. In key areas, selected through economic and technical analysis, the birth of national companies or even Latin American companies could be promoted.

These companies should be given a non-frivolous protection (Fajzylber, 1983), but that which would enable them to consolidate their position in the market place, following an apprenticeship trajectory.

## Fiscal Incentives

It is an indispensable requirement that the productive sector provide a greater contribution to the national research and development effort. This idea may be considered as indispensable to foster self-determination in biotechnology. For this reason, the Government must provide the necessary take-off impulse through fiscal incentives in recognition of R&D activities, for creating the corresponding infrastructure and for information, as well as for the training and development of human resources.

## Purchasing Policies of the Public Sector

It is worth considering that the main "promoter" of technological development is the market place and, in as much as the State is the largest buyer in any country, its role as a promoter of national technologies would be of the first magnitude, guiding its purchases towards those goods produced by means of these technologies.

## Quality Regulating Institutions

It has been demonstrated that biotechnology application is not free from dangers. On the face of this, it is imperative that governments should have an "alertness" attitude.

Courses should be organized on the safety measures in this new industrial area; manuals and procedures of quality and safety should also be written and disseminated.

On the other hand, it might be advisable to create a network of quality centres in support of the above actions, with the ability to provide certifications guaranteed and recognized by the different governments.

This last point may even lead to the creation of a "national certificate of quality", to be obtained by every company wishing to sell biotechnological products. Thus, the countries would gain in experience and would control those products to be marketed in their territories. Besides, research on the subject matter should be clearly regulated.

## Biotechnological Development Support Services

Technology development, its adaptation and assimilation frequently require interaction of technological agents providing the engineering aspects of the project, specialized information and design of equipment. With respect to Mexico, and from the standpoint of the supply, engineering firms have developed a technical capacity in branches such as civil engineering and certain fields of the chemical industry.

We have achieved excellence in detailed engineering and process design. However, lack of capacity in industrial and basic engineering continues. To correct this, linkages between engineering firms and national research centres should be promoted and strengthened, in such a way that demand for basic engineering and equipment be increasingly oriented towards supplying the domestic requirements.

Also, with the increase in demand for their services, a trend would develop towards a greater specialization of consulting and engineering firms, thus increasing their quality and reliability, as critical factors in the installation of biotechnological industries.

### Connection Between Research and the Productive Sector

It has been shown that, in modern biotechnology, interaction between research centres and the productive sector is critical. This interaction in Mexico is just beginning. It is necessary that research centres, industry, as well as government institutions promote this connection.

### Industrial Property

Mexico already has a modern industrial property law, adapted to the legislation of the more advanced countries. Consequently, it cannot be delayed that researchers, producers, corporations and the bulk of society be informed not only about the benefits, but also of the risks involved in granting temporal patent monopolies.

In addition to promoting biotechnology inventiveness, special care should also be placed on the information aspect of the patent. In exchange for the legal privilege, the inventor must reveal his invention. For this measure to fulfil its objective of promoting the flow of knowledge, the patent office must actively disseminate information on patents. This implies establishing a powerful technical information dissemination system incorporating all the latest advances in telecommunications and computational sciences (Solleiro and Arriaga, 1990).

## Final Comments

Biotechnological development entails many difficulties for the developing countries, but the benefits that may be obtained from its appropriate application more than cover the risks involved.

One of the main problems to be resolved is the identification and timing of markets to be developed. This opportunity detection cannot be based only on moments of inspiration. The developing countries must understand the dynamics of the techniques involved and of the biotechnology markets, and this will only be achieved through the concerted action of universities, research units, government institutions and corporations.

The apprenticeship process will be long and must incorporate, not only an accumulation of scientific, technological and manufacturing capacity, but also a close interaction with social needs and realities of the marketplace.

# Case Studies

**Anaerobic Treatment of Waste Waters**

The situation with regard to the infrastructure for the prevention and control of the contamination of water in Mexico is alarming, due to the limited number of treatment plants which exist and their low efficiencies. Most plants are aerobic, which in themselves lead to health and environmental problems. The newer anaerobic processes can contribute to environmental protection at reasonable cost. In Mexico it is now possible to design, build, start-up and operate anaerobic treatment plants. A team of researchers based at the Institute of Engineering at the National Autonomous University has transferred the technology, trained specialists and developed basic and applied research to support the establishment of anaerobic technology in Mexico. A private company has developed the technology package incorporating the reactor and microbiological cultures. Several sources of funds from national and international bodies as well as local industry supported these developments.

**Medical Diagnostics**

Mexico, like many developing countries, urgently is seeking new methods to be able to identify, at an early stage, and rapidly., the major diseases affecting its people- cholera, malaria, AIDS etc. In Mexico success has been achieved in the technology of production of monoclonal antibodies and their conservation and more recently on hybridoma technology, so that now there is a variety of monoclonals available for clinical and therapeutic diagnostics. A major centre for this work is the Institute of Biomedical research at UNAM which has developed diagnostics for detecting amoeba, tapeworm and malaria.

Other major developments underway in Mexico are in the production of human insulin, aspartame and bovine somatotropin.

**Micropropagation of Fruits and Ornamental Plants**

The technology of tissue culture for the micropropagation of plants has been worked on in the public sector for many years. Only recently has the private sector become interested and has promoted research to overcome difficulties of scale-up, quality control and inputs. Biogenetica Mexicana, began in 1989 to produce ornamental plants using tissue culture in a pilot plant in borrowed premises. It is now one of the largest micropropagation companies in Latin America, with well equipped tissue -culture laboratories and infrastructure. The Centre for Peasant Training and Demonstration, started by the Banco de Mexico, has been set up to train small-scale farmers in micropropagation through short courses, so that they could apply these techniques in their farming practices.

# Acknowledgement

Rosa Luz González and Sonia Zamudio contributed with valuable ideas and information to the preparation of this work, which was financed with funds provided by the International Development Research Centre. Fidela Rangel contributed with the heavy typing work.

To one and all my most sincere thanks.

The opinions expressed are the exclusive responsibility of the author.

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# Role of Biotechnology in Development of Zimbabwe

*C.J. Chetsanga*

*Department of Biochemistry, University of Zimbabwe, Mount Pleasant, Harare, Zimbabwe*

## Abstract

*This paper presents a brief analysis of the role that biotechnology can play in promoting agricultural, biomedical and industrial sector development in developing countries. It is argued that the mastering of clonal propagation techniques can be an effective approach to be used in entering the field of biotechnology by developing countries.*

*The paper gives a prioritisation of the principle fields that have been identified for focus in the Zimbabwe biotechnology programme. A summary of some of the resources and facilities available for biotechnology research and some of the current applications of biotechnology in Zimbabwe are outlined.*

*Among the items highlighted for Zimbabwe are the launching of the M Sc degree in biotechnology in 1991 at the University of Zimbabwe, and the decision by Government to establish a national Biotechnology Research Institute.*

## Introduction

The recent breakthroughs in molecular biology have transformed biotechnology into a precision science. These developments have brought in further refinements to areas like protein chemistry, nucleic acid biochemistry, fermentation and immunology. Biotechnology is an applied science which represents a blending of the principles and practice of biochemistry, genetics and microbiology.

The applied nature of biotechnology makes it an attractive field for developing countries because its results readily lend themselves to commercialisation. Expert manpower shortages constrain developing countries from significantly exploiting the opportunities offered by biotechnology. For these countries a strategy for embracing biotechnology is to begin by investing heavily in capacity building.

## Developmental Role for Biotechnology in Zimbabwe

Agriculture is the mainstay of the Zimbabwe economy. Some crops are grown for their commercial value while others are grown for food security.

The main draw back to agriculture in Zimbabwe is the frequent occurrence of drought periods. An important role that biotechnology can play in Zimbabwe is its application in developing drought resistant plants. Such a development would enhance the agricultural productivity of the country. If the application of biotechnology were directed at crops that are grown by small scale farmers, this group of farmers would benefit from biotechnology in a major way.

## Biotechnology Priority Fields in Zimbabwe

The priority setting process has been catalysed by the Research Council of Zimbabwe (RCZ) which has convened workshops at which leading scientists participated. The discussions at these meetings highlighted the importance of the acquisition of biotechnology skills by the country.

The first project recommended for implementation was the launching of the M Sc Biotechnology in 1991. The first group of trainees will complete the degree at the end of 1992.

The second project launched was the establishment of the Biotechnology Research Institute. The construction phase will start in 1992 with completion expected in 1994.

The principle fields that have been identified for the Zimbabwe biotechnology focus are: Crop Production; Livestock Production; Horticulture; Food Processing; Vaccine Production; and Fermentation Technology

## Resources and Facilities for Research

The facilities currently available for biotechnology research are located at the University of Zimbabwe (Departments of Biochemistry, Biological Science and Crop Science). These facilities are being used for both research and teaching. The equipment inventory includes: 8 sets of electrophoresis apparatus; 4 ultracentrifuges; 4 laminar flow hoods; 4 shaken water baths; 3 MP-4 Polaroid cameras and transilluminators; 2 PCR machines; several microcomputers; several microscopes; 2 CO2 incubators; several freezers; several refrigerators; 2 liquid scintillation counters; and 2 tissue culture rooms.

The amount of funds available for biotechnology per year is about US$200,000. The amount varies from year to year. The funds are used for purchasing equipment radioisotopes, restriction enzymes, Taq polymerase, electrophoresis expendables, and paying research staff salaries.

# Biotechnology Applications

In my view, the most practical entry point into biotechnology for a developing country is cell biotechnology. The most promising early applications of biotechnology are in micropropagation. This involves the dissociation of tissue cells and culturing them to achieve the production of disease-free seedlings by clonal propagation.

The Tobacco Research Board is establishing a Biotechnology laboratory. They are interested in developing varieties of tobacco seedlings enriched in specific properties (pest-resistance or drought-resistance). Most of the research at the agricultural Department of Research and Specialist Services under the Ministry of Agriculture is based on traditional biotechnology.

A lot of biotechnology mileage can be gained by the use of micropropagation techniques to produce uniform plant material for protoplast fusion experiments, export and for establishing industrial plantations. Micropropagation can be fruitfully used in developing seedlings for agro-forestry. This approach was used in developing orchid clones. A companion technology to be acquired is tissue culture. One can isolate cell clones of the needed crops in a virus-free state.

After successfully developing a country's cell biotechnology programme to the point of routinely applying it in micropropagation of plant material, the next stage is to gradually move into molecular biotechnology. (Examples of current work are provided in the case studies at the end of this paper.)

The entry into molecular biology based biotechnology (recombinant DNA technology) to create genetically modified organisms (GMOs) can come in the next phase. The tooling up for capability in gene cloning is a long and expensive process. There is a need for a critical mass of trained molecular biologists. The choice of projects on which to focus is critical.

There are a number of projects currently underway in which biotechnology is being applied in health and industrial research. Most of these projects are being pursued at the University of Zimbabwe. A project in Dr Feresu's laboratory is focused in isolating and characterising milk fermenting bacteria. The aim is to optimise the traditional process of milk fermentation and improve its acceptability to the Zimbabwe consumer.

Another project is investigating the cattle aborting bacteria occurring in the Zimbabwe natural environment. The aim is to develop a DNA diagnostic probe that can be used as an easy and fast assay for detecting the strains of Leptospira interrogens that causes abortions in cattle.

Dr Gopo's laboratory has developed a Salmonella DNA probe for screening food, animal feed and water for Salmonella contamination. This probe is being optimised for field applications.

Dr Robertson's laboratory is using the clonal propagation technique to produce potato seedlings. He hopes to provide a service for supplying potato seedlings to small scale farmers.

My laboratory is studying the genome of hepatitis B virus. We are focusing on developing a database on the polymorphism of the nucleotide sequence of the S-gene (encoding the surface antigen HBsAg) responsible for immunogenicity in people. We are also working to produce s-gene constructs that give greater genetic activity in HBsAg production.

These few examples show the wide variety of biotechnology projects being carried out in Zimbabwe. As we get more trained biotechnologists, there is great scope for creating a critical mass of biotechnologists in the next five years. We expect to have expanded our biotechnology equipment during this time period.

## Government Support and Policy Guidelines

Biotechnology has been highlighted as a critically needed technology in Zimbabwe's national Science and Technology (S&T) Policy Statement. The policy proposes that the early focus of the national biotechnology be directed at crop and livestock improvement. The main objective will be to develop high yield varieties.

In recent months, there has developed a recognition of the importance of making provisions for biosafety. This has been influenced by a rapidly developing awareness in Zimbabwe.

The RCZ is engaged in an effort to develop biosafety guidelines. It is hoped to develop a system of voluntary compliance. There are only two laboratories involved in recombinant DNA technology work. The power of this technology is not fully understood by the majority of this largely peasant population. It is expected that there will be more calls for greater control of recombinant DNA work when the level of awareness increases. In the meanwhile scientific leaders are emphasising the importance of best laboratory practice in the conduct of work in biotechnology as the required approach to biotechnology.

The area of intellectual property rights (IPR) is beginning to receive attention. This arises in part from the fact that Zimbabwe is a member of the African Regional Industrial Property Organisation (ARIPO). Many African countries belong to ARIPO.

The issues that were considered when the early ARIPO discussions addressed industrial property rights are very much relevant in biotechnology. Government has not yet got down to the point of designing legislation to deal with biotechnology IPR.

My own laboratory is studying the S gene of hepatitis B virus (HBV) DNA. We have cloned both the pre-S region and the S gene region in vector pIBI31. We are currently comparing nucleotide sequences of the combined pre-S plus S gene sites from a number of Zimbabwean HBV isolates. We want to determine whether the nature of the sequences in this region influences the immunogenic efficacy of the HBsAg protein encoded by this region.

# Constraints to Flourishing of Biotechnology Applications

Although biotechnology has great potential for promoting sustainable socio-economic development in developing countries in Africa, its benefits are still hard to realise because of a number of constraints.

The major constraints are in the area of shortages of skilled manpower, equipment and facilities including funds for recurrent expenditures. For a country to benefit from biotechnology, it must first invest in these areas. In my view the most important investment in tooling up for biotechnology is in manpower development. As training is currently available almost exclusively overseas, and African countries are experiencing their hardest times economically, the only viable access to this technology is one funded by donors.

One would like to encourage the launching of special scholarships by the international community to enable African trainees to acquire biotechnology. If such a programme were launched and carefully targeted, it would take about ten years for a significant number of African countries to acquire biotechnology.

# Case Studies

**Cassava Study**

As cassava is not used much as a food item in Zimbabwe, the main interest in growing it on a large scale is its industrial processing for plastics, carbohydrates, etc. Dr Ian Robertson's laboratory at the University of Zimbabwe is initiating the expanded research on cassava breeding in conjunction with some rural community groups. Government extension agencies are promoting the growth of cassava so that it can serve as a hedge against the impact of drought years.

Use is being made of micropropagation techniques. The technical problems associated with attempts to use molecular gene transfer techniques are well known by experts in this field. Thus the use of molecular gene cloning in cassava breeding has not yet been achieved.

The results from introducing cassava are likely to benefit a wide cross-section of the Zimbabwe community as the country's extension system is being mobilised to ensure a wider distribution of the results. It is hoped that wider cassava growing can eventually lead to its acceptance as a food crop in Zimbabwe.

**Hepatitis B Virus and Liver Cancer**

Primary liver cancer is the leading cause of cancer related fatalities in Zimbabwe. Its early diagnosis can result in prolongation of the life of the victim. Hepatitis B virus is implicated in liver cancer carcinogenesis. The hepatitis B virus (HBV) study has used a DNA probe to screen the blood of a large segment of the Zimbabwe population for the prevalence of HBV infection. Blood samples served as sources of HBV, which was cloned and its surface antigen gene sequenced to identify its nucleotide sequence structure.

The work is being done in Professor C.J. Chetsanga's laboratory at the University of Zimbabwe. Current work seeks to clone the isolated gene in an expression vector from which significant surface antigen proteins can be purified for use in vaccine trials.

Successful production of recombinant DNA HBV vaccine would provide an opportunity for going into other pharmaceutical study applications.

**Salmonella Probe**

Salmonella food poisoning is a common medical problem in developing countries and to some extent in developed countries. It has long been recognised that methods of detecting Salmonella in food samples can be very effective in preventing food poisoning by this pathogen.

Dr Gopo's laboratory at the University of Zimbabwe has been working on developing DNA probes for diagnosing food contamination by Salmonella. They have identified a DNA probe isolated by fractionating restriction digests from the Salmonella genome. The fragment isolated has proved to be a sensitive probe for screening foodstuffs for contamination by Salmonella.

Dr Gopo and his colleagues have been actively using the DNA probe to assist butcheries and restaurants in screening meat and foodstuffs for Salmonella contamination.

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