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BIOTECHNOLOGY AND SUSTAINABLE AGRICULTURE: THE CASE OF MEXICO

by

José Luis Solleiro Rebolledo

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RÉSUMÉ

Cette étude de cas sur le Mexique analyse l'évolution des biotechnologies destinées à l'agriculture, au regard des récentes réformes intervenues dans les politiques macro-économique, environnementale et agricole, ainsi que dans l'industrie de production de semences, la protection de la propriété intellectuelle et la sécurité biologique. Elle identifie également les incitations et les obstacles qui influent sur les différentes phases de la recherche, du développement des technologies et de la diffusion des biotechnologies dans l'agriculture.

L'auteur avance que, dans les conditions actuelles, les biotechnologies pourraient ne bénéficier qu'aux producteurs qui sont déjà en mesure de tirer avantage d'ensembles technologiques relativement complexes, tandis que les petits paysans en seraient écartés. En conclusion, il formule des recommandations pour élaborer une politique des biotechnologies au service du secteur agricole.

SUMMARY

This case study of Mexico examines developments in agricultural biotechnology against the background of recent changes in macro-economic, environmental and agricultural policies as well as in the regulation of the seeds industry, intellectual property protection and biosafety. It also identifies incentives and constraints at the different phases of research, technology development and diffusion of biotechnology in agriculture.

The study suggests that, under current conditions, biotechnology is likely to benefit only those producers already taking advantage of relatively complex technological packages and to bypass small farmers and peasants. It concludes with recommendations for the establishment of a biotechnology policy for the agriculture sector.

PREFACE

This paper is part of a research project entitled "Biotechnology and Sustainable Agriculture", which has been undertaken in the context of the Development Centre's 1993-1995 research programme on "Sustainable Development: Environment, Resource Use, Technology and Trade". This project analyses developments in agricultural biotechnology research, development and diffusion in order to determine whether biotechnology is likely to contribute to a more sustainable model of agricultural production. This alternative model would be less dependent on the use of agrochemicals and based more on biological pest and disease control and local genetic resources.

The research comprises a number of different components. These include a conceptual study of agricultural biotechnology in the context of a national innovation system and an analysis of publicly-funded international initiatives to stimulate the introduction of biotechnology in agriculture. In addition, six country studies have been conducted: India and Thailand in Asia; Colombia and Mexico in Latin America; and Kenya and Zimbabwe in Africa. Country studies, which have identified both successes and failures in biotechnology initiatives, have sought to determine incentives and constraints in the successive phases of research, technology development and diffusion of biotechnologies for plant protection and production.

This study of Mexico indicates that an appropriate policy and legal framework to promote sustainable agricultural development are already in place. In addition, the opening of the economy and the participation of Mexico in NAFTA constitute powerful pressures in favour of modernisation of the agricultural sector and innovation in agriculture.

The study nevertheless highlights a number of factors which inhibit the development and diffusion of biotechnology in agriculture. It argues that under present conditions, few incentives are in place to stimulate the demand for biotechnology products on the part of small farmers and peasants. It also concludes that, without effort to modify the constraints, Mexican biotechnology will continue to be "pushed" by scientists without strong links to production, and demand pull will remain weak.

Jean Bonvin
President
OECD, Development Centre
December 1994

I. INTRODUCTION

During the past two decades, improvements in agricultural productivity have been largely based on the introduction of a technology package including high-yielding plant varieties, intensive use of chemical fertilisers, herbicides and pesticides, and abundant supplies of water. Despite undeniable success in raising productivity, concerns exist about the environmental sustainability of this model. Use of large amounts of agrochemicals has caused severe soil and water pollution, and the development of strains resistant to pesticides. Water resources are becoming increasingly scarce. Moreover, the genetic base of many important high-yielding varieties is increasingly uniform and, as a consequence, they are susceptible to unpredictable outbreaks of disease and to the harmful effects of plant pests. However, thus far relatively few farmers in developing countries have had access to this new technology and capital-intensive methods of production.

Nonetheless, the emerging biotechnology revolution is stimulating hope that it can provide the basis for a more sustainable agriculture in developing countries. This is because the new biotechnologies are different from previous agricultural technologies in two ways. First, biotechnology can be used to enhance product quality by improving the characteristics of plants and animals. Second, biotechnology has the potential for conserving natural resources and improving environmental quality by using organisms for degradation of toxic chemicals and wastes, fertiliser and soil improvement, and the development of insect- and disease-resistant plant varieties. Many of these applications are now, or will soon be, a reality, and they can have far reaching consequences for the solution of important problems in developing countries. But given the increasing control over innovation and markets for the new biotechnology products, it has to be asked whether biotechnology is really likely to contribute to more sustainable methods of agricultural production in developing countries.

This country study on Mexico will try to answer this question by identifying the major institutional and policy incentives for the development and diffusion of biotechnology products on the one hand, and the constraints, preventing or limiting use of the new biotechnology on the other.

In recent years, Mexico has carried out some sweeping macroeconomic policy changes, making a rapid transition from a protected to an open economy. Thus the case study begins with a brief presentation of current agricultural policies, including an analysis of the main instruments introduced by the government. The environmental policy, which is related to a more sustainable model of agricultural production, is also analyzed. The section after that discusses the competitiveness of Mexican biotechnology, giving special attention to the capabilities for developing biopesticides and other biological methods of plant protection.

The next section examines current programmes for promoting research and commercial applications of biotechnology in Mexico. The potential benefits of biotechnology depend on its diffusion, and from that standpoint there is a review of the links between biotechnology research and the traditional agricultural research system, as well as of the obstacles to the adoption and commercialization of new biotechnology products.

The study concludes with some recommendations for policies to encourage the development of biotechnology in Mexico and a wider use of biotechnology in Mexican agriculture, regardless of its source.

II. METHODOLOGY

This case study has involved intensive consultation with researchers, civil servants, and representatives of farmers' associations, who were asked to discuss the possibilities for the introducing biotechnologies — especially biopesticides — in Mexico's agricultural sector, and the potential of these techniques for inducing more sustainable systems of production. We have used a broad concept of biotechnology which "includes any technique that uses living organisms, or substances from organisms, to make or modify a product, to improve plants or animals, or to develop microorganisms for specific uses" (Cohen, 1994).

Sustainability, the study's other basic concept, is defined by the FAO as: "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development in agriculture conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable".

In assessing biotechnology's expected contribution to an alternative, more sustainable agriculture in Mexico, we did the following things:

1. We organised a small working group consisting of a biologist, an agronomist, a biotechnologist, a food technologist, an economist and a technology manager to develop an interdisciplinary approach for analysing this complex problem.

2. To provide a context for analysing the effects of biotechnology on agriculture, the general macroeconomic, agricultural and environmental policy background was studied by reading the main official documents and by interviewing major actors in the agricultural sector and representatives of the biotechnology industry.

3. We also analyzed the recent evolution of Mexico's science and technology policies and the initiatives to formulate and implement specific national biotechnology programmes.

4. We identified the principal institutions involved in research and development in biotechnology, giving special attention to those with projects or capabilities for the development of biopesticides and other methods of plant protection.

5. This information was used to assess the competitiveness of Mexican biotechnology, with the aim of identifying the main constraints to the development and diffusion of biotechnology in the agricultural sector.

6. To refine this assessment, we made case studies of R&D projects and biotechnology enterprises. Information from researchers and entrepreneurs also has been very useful for obtaining a more precise picture of the major obstacles and the possible ways of overcoming them. These interviews have supplied information for evaluating current scientific, agricultural and industrial policies.

7. Finally, the findings were first presented in a workshop dealing with the main concerns of this and other country studies. The discussions at the workshop stimulated new ideas and provided feed-back on recommendations for future policies to promote the development and use of biotechnology in Mexican agriculture.

III. GENERAL OVERVIEW OF THE AGRICULTURAL SECTOR AND THE NEW DEVELOPMENT POLICY

Agriculture has played an important role in the growth of the Mexican economy. Indeed, after the halt of agrarian reform that began at the end of the 1930s, the agricultural sector had high growth rates as a result of increases in the cultivated area, access to a cheap work force, and the expansion of irrigated lands with considerable state support.

During the 1950s, government policies facilitated the use of more capital-intensive agriculture and promoted the transfer of technology. This technology led to increased crop yields under the Mexican version of the "green revolution". However, this modernization process was rather fragmentary. Only the large landowners engaged in commercial agriculture could fully incorporate the technological changes. The *ejidatarios* (communal farm workers) generally did not have access to the technical assistance and capital necessary for the new technology. As a result, different forms of production came to exist side by side, manifested by large inequalities in incomes.

About 1965, the agricultural sector began to decline, with a loss of dynamism in the production of basic grains, which led to a loss of self-sufficiency in foodstuffs and a growth of imports. Indeed, agricultural growth fell to a level less than the growth in population, and the agricultural sector's share of exports declined from 52.7 per cent of total export in 1960 to 48.3 per cent in 1970, 10.1 per cent in 1980 and 6.1 per cent in 1985 (R. Oranday, 1990). Agricultural imports, which were $22 million, or 1.9 per cent of total imports in 1960, increased to $1.6 billion (11.4 per cent of the total) in 1985, and by 1992 had reached almost $2.9 billion (21.7 per cent of the total).

To a large extent, the fall in agricultural production has been due to low average yields, a result of poor assimilation of technology and a process which has concentrated profitable production in only one eighth of the area under cultivation. Thus production of all basic food crops decreased while, in response to the growth of industry and livestock raising, the development of fodder and oleaginous crops accelerated. At the beginning of the "lost decade" of the 1980s, the government launched a programme to regain self-sufficiency in foodstuffs, called the Mexican Food System (SAM), which introduced substantial subsidies to promote the production of basic foodstuffs, primarily maize and beans. The SAM stimulated the sector and some industries supplying inputs, such as seeds, but it had a fleeting existence. SAM disappeared after the petroleum crisis drastically decreased the state revenues. The agricultural crisis was intensified by its continuing unfavourable terms of trade with industry. As a result, labour continued to migrate from the countryside to the cities, but industry has been unable to provide jobs for this labour force, which has moved towards the service sector and increased the marginal urban population.

Today, agricultural policy is defined within a radically different economic context. Mexico has discarded the import-substitution model and a protected economy in favour of export promotion and insertion in the global market. The strategy for modernizing the Mexican countryside is based on free trade and the promotion of new forms of organised participation of the *campesinos* (peasant farmers). Article 27 of constitution and the agricultural legislation concerning farmers' rights have been modified to legitimise the privatization of land as the state ends its direct intervention in the organization of agricultural production. This will facilitate further concentration of land and production, especially because these modifications occurred during the agricultural difficulties resulting from the "adjustments" of the lost decade. The government is now directing its attention to the impoverished *campesinos*, attempting to get them to participate in more capital-intensive agriculture by promoting new economic relationships that have been very successful in commercial agriculture, notably the *"asociaciones en participación"* (participatory associations), under which *campesinos* and small farmers establish agreements with agroindustrial enterprises, which provide technology and financing in exchange for a reliable supply of agricultural raw materials.

After Article 27 of the constitution had been amended and the corresponding agrarian law was revised on 27 February 1992, the state launched a Modernization Programme for the Agriculture Sector whose main points are described below.

Budgetary Resources and Financing

The President had promised that the proportion of the budget devoted to the countryside would increase, but despite a financial restructuring the figures show exactly the opposite (Tables 1 to 5). In reality, financing is considered one of the main obstacles faced by the country in achieving its modernization objectives. In this respect, the main policy guideline is that credit must no longer be a sort of indiscriminate subsidy but must become an instrument for promoting productivity. Three main types of producers were identified for the purpose of the different financing bodies.

a. Producers in the marginal zones who are supported by the National Solidarity Programme (PRONASOL) by means of state Funds for Productive Reconversion. PRONASOL is a social programme which channels resources for infrastructure in the most economically backward rural and urban zones. In this case, it is clear that support is linked to a productive conversion process requiring access to technology and organization which are still beyond the reach of these producers.

b. Producers with low incomes but having productive potential whose needs will be met by the public financial system for the support of agriculture, primarily the National Bank for Rural Credit (BANRURAL), the Trust Funds Established in Relation to Agriculture (FIRA) and the Special Guarantee and Technical Assistance Fund for Agriculture and Fisheries Credits (FEGA), which have been charged with drawing up programmes for credit at preferential rates. It was also considered essential to encourage the establishment and strengthening of credit unions.

c. Commercial agriculture producers whose needs will be financed by the banks or programmes of FIRA, the National Financing Institute (NAFIN), the Fund for Commercial Development (FIDEC) and the National Foreign Trade Bank (BANCOMEXT).

These institutions have devised different mechanisms for improving access to credit. FIRA proposes instruments to subsidise the high operational and transaction costs imposed by the commercial banks. NAFIN will establish an Investment and Capitalization Fund for the Rural Sector (FOCIR) for choosing and financing investment projects.

In spite of all these programmes, the portfolio of overdue loans payable to the commercial banks in 1993 was over $5 billion while that of the public sector banks was over $3.5 billion.

Both the commercial and development banks have decreased the amount of rural credit. According to BANRURAL officials, demand for financing agricultural equipment has dropped sharply. This a negative indicator for the agricultural sector's technical development and capitalization that BANRURAL is supposed to promote.

Domestic Trade

The commercialization process has also been reorganised for the purpose of developing the distribution and commercialization network, preventing monopolies in the domestic supply system and allowing producers and intermediaries to be rewarded according to their productive effort. For this purpose the policy guidelines have the aim of developing regional markets and encouraging the establishment of a larger number of reception and distribution centres.

Thus the National Company for the People's Subsistence (CONASUPO) has withdrawn from the commercialization of almost all products, with the exception of maize and beans, and has also modified its storage and transport prices while eliminating subsidies. At the same time, a new decentralised agency of the Ministry of Agriculture and Hydraulic Resources (SARH) was created, the Support and Services for the Commercialization of Agriculture and Fisheries (ASERCA), with the objective of promoting the organization of producers for commercialization and for obtaining credit to support commercialization, and the establishment of specialised commercialization enterprises.

ASERCA began to function in 1993 by providing support for the reception, storage, transport and purchasing operations of important products like sorghum, wheat and soy beans. A modern system of information on prices, supply and demand has also been put into operation. This system has satellite communication links with the main agriculture exchanges throughout the world.

Table 1. **Public Expenditures for Agriculture**
(Billions of Pesos)

All Economic Sectors				Rural Development and Fisheries (RDF)			
Year		$ Constant 1978=100	%		$ Constant 1978=100	%	Growth Rate (RDF)
1986	17 187	418.35	100	1 714	41.73	9.98	-28%
1987	39 223	368.39	100	3 210	30.15	8.18	-28%
1988	74 222	459.65	100	4 537	28.09	6.11	-7%
1989	288 273	1491.49	100	5 022	25.98	1.74	-8%
1990	117 122	466.39	100	6 709	26.71	5.73	3%
1991	148 879	499.05	100	7 146	23.95	4.80	-10%

Source: IV Informe de Gobierno (1992)

Table 2. **Total Area Supported by Banrural**
(Thousands of Hectares)

Year	Irrigated	%	"Temporal"	%	Total	%	Growth Rate Total
1985	1 666	23	5 508	77	7 176	100	
1986	1 656	23	5 584	77	7 240	100	1
1987	1 621	22	5 824	78	7 445	100	3
1988	1 503	21	5 765	79	7 270	100	-2
1989	1 205	22	4 274	78	5 479	100	-25
1990	928	48	1 023	52	1 951	100	-64
1991*p*	578	47	658	53	1 236	100	-37
1992*e*	700	50	707	50	1 407	100	14

p = Preliminary
e = Estimated

Source: IV Informe de Gobiemo, Anexo Estadistico.

Table 3. **Working Capital Financed by Banrural**
(Millions of Pesos)

Year	Irrigated			"Temporal"			Total		
		$ Constant 1978=100	%		$Constant 1978=100	%		$Constant 1978=100	%
1985	145 809	7 302.50	46	169 737	8 500.88	54	315 546	15 803.38	100
1986	235 247	5 726.28	44	293 648	7 147.85	56	528 895	12 874.13	100
1987	517 840	4 863.63	46	616 864	5 793.67	54	1 134 704	10 657.30	100
1988	1 045 720	6 476.13	40	1 600 486	9 911.79	60	2 646 206	16 387.92	100
1989	940 238	4 864.67	35	1 746 688	9 037.13	65	2 868 926	13 901.80	100
1990	979 077	3 898.73	56	768 883	3 061.73	44	1 747.960	6 960.46	100
1991p	826 825	2 771.56	55	687 528	2 304.63	45	1 514.353	5 076.19	100
1992e	1 255 396	3 759.36	60	845 873	2 533.02	40	2 101 269	6 292.37	100

p = Preliminary
e = estimated
Source: IV Informe de Gobiemo, Anexo Estadistico

Table 4. **Total Credit for Agriculture Supplied by Commercial Banks**
(Billions of Pesos)

Year	Total Primary Sector			Agriculture			
		$ Constant 1978=100	%		$Constant 1978=100	%	Growth rate of Agriculture
1985	717	35.89	100	620	31.03	86	
1986	1 015	24.71	100	790	19.23	78	-38
1987	2 487	23.36	100	1 892	17.77	76	-8
1988	5 432	33.64	100	4 096	25.37	75	43
1989	9 570	49.51	100	7 879	40.76	82	61
1990	15 291	60.89	100	13 267	52.83	87	30
1991p	22 953	76.94	100	18 393	61.65	80	17
1992e	25 393	76.04	100	20 811	62.32	82	1

p = Preliminary
e = estimated
Source: IV Informe de Gobiemo, Anexo Estadistico

Table 5. **Total Credit for Agriculture Supplied by Development Banks**
(Billions of Pesos)

Year	Total Primary Sector			Agriculture			
		$ Constant 1978=100	%		$ Constant 1978=100	%	Growth rate of Agriculture
1985	1 299	65.07	100	648	32.43	50	
1986	2 711	65.98	100	1 028	25.03	38	-23
1987	6 526	61.27	100	1 799	16.90	28	-32
1988	9 221	57.10	100	4 134	25.60	45	51
1989	10 068	52.09	100	5 655	29.26	56	14
1990	9 928	39.53	100	8 121	32.34	82	11
1991p	7 095	23.78	100	6 437	21.64	91	-33
1992e	7 562	22.64	100	7 134	21.36	94	-1

p = Preliminary
e = estimated
Source: IV Informe de Gobierno, Anexo Estadistico

Foreign Trade: Mexican Agriculture and the Free Trade Agreement

The policy of promoting foreign trade in agriculture, fisheries and forestry products comes under the general strategy of integrating the national economy into international trade. Mexico signed a Free Trade Agreement with the United States and Canada (NAFTA) which has become the "economic Bible". NAFTA came into effect on 1 January 1994 and has created a free trade zone encompassing the three countries. It has accentuated the challenges confronting Mexico since it became a member of the GATT. To facilitate the free circulation of goods and services envisaged by NAFTA, tariffs will be removed over periods of five, ten and even 15 years, and mechanisms will be established to reduce all non-tariff barriers (such as sanitary, phytosanitary and technical regulations in the case of agriculture) that represent an obstacle to trade.

NAFTA's chapter on the agriculture sector covers five areas as follows:

Domestic Subsidies

Given the distortions generated by domestic supports, it has been agreed that if one party decides to support its agricultural producers, that party shall make efforts to adopt policies which have minimal distorting effects on trade and production, and which are exempt from commitments to reduce domestic support under the GATT. For Mexico, this means changing its system of agricultural support from one based on commercial protection to one based on a system of direct payments to producers to promote conversion of production. Indeed, the text recognises subsidies to be a development policy for agriculture and fisheries.

Export Subsidies

The use of export subsidies will be subject to the approval of a trilateral committee to prevent unfair competition. Under the Agreement the parties are committed to ending export subsidies in agricultural trade, but this is already showing signs of being easier to promise than to implement, given the systems in operation in Canada and the United States. Arguments have already begun over wheat export subsidies.

Sanitary and Phytosanitary Provisions

The text establishes rights and basic obligations for the three countries and defines the fundamental role that international norms play. It also states that the countries shall be able to impose more rigid standards if the international standards do not provide an adequate level of protection. These provisions represent a powerful stimulus for transforming the technological basis of Mexican agriculture towards more sustainable production methods.

Quality Norms

When one of the countries adopts a measure for standardizing an agricultural product, the country applying the measure shall not give less favourable treatment to similar imported products.

Market Access

NAFTA contemplates the removal of all tariffs over a period not exceeding 15 years, and non-tariff barriers will be removed in accordance with the procedures adopted in the Uruguay Round of the GATT.

Insurance

As in the case of financing, producers are divided into different categories for the purpose of insurance. The strategy contemplates supporting private and official insurance institutions for producers in regions with a high productive potential. Producers with a high incidence of claims are assisted by PRONASOL. Insurance funds are also being promoted. These funds will come from the producers but the Federal government subsidises 30 per cent of the insurance premiums. Under this system, the area insured increased from 327 000 hectares in 1991 to more than one million hectares in 1992.

Inputs

Agricultural policy recognises the importance of having access to the inputs necessary for products to be competitive. Thus the need for permits to import agricultural machinery and equipment has been abolished. The indirect subsidy for fertilisers will gradually be abolished and the state company producing these inputs has been privatised.

Customs duties on the import of improved varieties of seeds were removed due to the lack of quality prototypes in the country. The National Seed Producer drastically reduced its operations. This indicates that the supply of seeds will be determined by market forces.

This same philosophy underlies the policy under which the system of guaranteed prices was abolished, to be replaced by one in which prices will be based on the behaviour of prices on the international markets, taking into account that domestic prices on basic crops have been higher in recent years. It is expected that from now on Mexican producers, facing international competition, will have to produce at lower costs and sell at competitive prices. An agricultural exchange is also being established to help assure producers, in advance, of a sales price for their products.

In 1993, the Support Programme for the Countryside (PROCAMPO) was launched, the last major agricultural policy of the current administration. Its purpose is to compensate for the subsidies provided by other countries to some agricultural producers and to promote productive reconversion of crops that could benefit from the country's comparative advantages. PROCAMPO is to channel direct economic support to producers according to the area sown with maize, beans, wheat, rice, sorghum, soy beans and cotton. This support will gradually become a substitute for the subsidy on guaranteed prices. Thus productive operations will be aimed at highly profitable products. Many farmers and producer organizations believe that PROCAMPO will not encourage productivity because the amount of the subsidy is in no way linked to production. Under these conditions, according to Jorge Kondo, leader of an important farmers' association, "the farmer who produces less, without using fertilisers, weed-killers or certified seeds is the one who maximises his income. The impetus for seeking new technologies will be lost".

In short, the Mexican government has set in motion a process under which there will be competition to form large agricultural and agroindustrial units able to introduce technological change, produce at competitive prices and generate exportable surpluses. Foreign investment is expected to catalyze this process and help alleviate the unemployment that could appear in critical areas like subsistence agriculture. As mentioned, it is also believed that international prices will lead to lower costs of production, and thus tariffs on most inputs have been eliminated. Furthermore, subsidies such as for fertilisers, fuel, seeds, agricultural extension and training have begun to be abolished. The policies assume that Mexico can benefit from its comparative advantages and that the opening of markets and investment will be the keys to competitiveness. This approach leaves any strategic role for the agriculture sector on the side lines. To be sure, the present heterogeneous, undercapitalised and technologically backward agricultural sector holds little promise. Under these circumstances, much of the agricultural population will not have access to modern technology.

The New Environmental Policy

Mexico has recently adopted an ecological policy that reflects national objectives and also the obligations under international agreements such as those deriving from the United Nations Conference on the Environment and Development (Declaration of Rio, Agenda 21, Non-Binding Declaration on Principles for Forests, Framework Convention on Climatic Change, Framework Convention on the Protection of Biological Diversity). Furthermore, before NAFTA went into effect, it was also necessary to negotiate a subsidiary agreement on environmental protection.

Thus the government takes into account considerations on the environment and sustainable development in the following areas:

— Inclusion of environmental considerations in economic and social policies
— Ecological policies and their instruments
— Legal and institutional framework.
— Fight against poverty
— Social participation
— Protection and promotion of human health
— Education, increasing of levels of awareness and training
— Science and technology for sustainable development
— International trade and environment

It is worth pointing out that ten priority areas have been defined for sustainable development, two of which are relevant for this study: sustainable agriculture and rural development, and biotechnology.

The present administration gave priority to environmental policy in the 1989-1994 National Development Plan. The National Programme for the Protection of the Environment was also approved with the objective of harmonizing economic growth with the re-establishment of the quality of the environment, promoting conservation and the best rational use of natural resources. Among its objectives are the prevention and control of soil pollution, the correct handling of dangerous substances, and preserving the quality of water and its optimal use.

The government has established ambitious programmes for education, research, training and diffusion of information on ecology and the environment, indicating that it considers scientific and technological developments important for improving the environment.

The technology associated with the green revolution in agriculture led to an indiscriminate use of agricultural inputs, which had deleterious effects on the environment. Excessive mechanization has produced compacted soil, while fertilisers and chemical pesticides have generated changes in soil pH which, in turn, impedes development of crops and contaminates water. There has been a significant increase of the consumption of fertilisers in the last 20 years (see Table 6). Most chemical pesticides and herbicides used in large-scale agriculture seep into the soil and generate long-term residual effects, poisoning animals and contaminating rivers and the environment in general.

Table 6. **Fertiliser Consumption**
(Kilograms per Hectare)

Country	1970-1971	1989-1990
Argentina	2.60	4.60
Belgium-Luxembourg	0.57	0.50
Brazil	18.60	43.00
Canada	19.10	47.20
China, People's Rep.	41.00	0.26
France	0.24	0.32
Germany	0.38	0.37
Italy	89.60	0.15
Japan	0.36	0.42
Korea, Republic of	0.25	0.43
Mexico	23.20	72.80
Netherlands	0.75	0.64
Spain	59.30	0.10
United Kingdom	0.26	0.35
United States	81.60	98.50

Source: World Bank, World Development Report, 1992.

These problems have been met by regulations dealing with pesticides, fertilisers and toxic substances, since their production, handling and use can present risks to health and lead to water, soil and air pollution. In recent years, there has been a considerable increase in imports of pesticides. The increases in imports in 1992 over the previous year for weed-killers was 69 per cent; fungicides, 34 per cent; insecticides and acaricides, 18 per cent; and nematocides, 17 per cent. To a large extent, these increases were probably due to the removal of customs duties on the products involved, but the situation was also revealing for the ostensible environmental policy. Moreover, use of pesticides can be quite dangerous, and in Mexico 11.5 per cent of acute cases of poisoning from pesticides result in death. For this reason, in 1988, poisoning from pesticides was included in the list of medical conditions for which reporting to the public health authorities is obligatory. An Interministerial Commission for the Control, Processing and Use of Pesticides, Fertilisers and Toxic Substances was created in 1987. This Commission consists of the Ministries of Health, Social Development, Agriculture and Hydraulic Resources and Trade and Industrial Development. Its functions include:

— Instituting procedures for the authorization of the production, transport and distribution and use of these products.

— Creating an inventory of substances, producers, importers, services and technological capacity related to the products.

— Reviewing and updating customs duties.

— Responsibility for the drawing up and issuing of official Mexican standards.

— Responsibility for a network of official laboratories, unifying methods of analysis.

— Studying the legal regulation of these substances and proposing technical and administrative modifications.

The Commission has drawn up the Official Pesticide Catalogue which lists pesticides whose use is restricted. In the 3 January 1991 Diario Oficial it also published a list of 21 pesticides, whose processing and use is prohibited, and a list of dangerous products (see Table 7), in accordance with the Basle Agreement. This is the background for an interministerial structure based on various laws containing provisions relating to pesticides, and toxic and dangerous substances (see Table 7).

Table 7. **Laws regulating the use of pesticides and other toxic substances**

Law	Application
Ley General de Salud (General Health Law)1992	— Health controls of economic activities, facilities, products, and services
Ley General del Equilibrio Ecológico la Protección de Ambiente (General Law for Ecological Equilibrium and Environmental Protection) 1992	— Dangerous waste — Prevention and control of atmospheric pollution — Prevention and control of water pollution
Ley de Sanidad Fitopecuaria (Phytosanitary Law) 1992	— Plant health control
Ley Federal del Trabajo	— Work safety and hygiene
Ley de Aguas Nacionales (National Water Law) 1992	— Prevention and control of water pollution
Nueva Ley Agraria (New Agrarian Law) 1992	— Promotion of sustainable agriculture

The New Agrarian Law of 26 February 1992 states that the public administration shall promote sustainable agriculture and scientific and technological research and the transfer of its results to all rural producers.

As can be seen, there is a complete legal and political framework for developing a sustainable agricultural. However, its application is not yet tangible. Mexico has a long way to go before it adopts a modern environmental outlook. Environmental protection is still considered to be a luxury reserved for the advanced countries. However, the government has begun to adopt strict measures to increase compliance with the law. This will accelerate the learning process, although it must not be forgotten that legislation alone is insufficient. Environmental education and research is still very limited.

The fact is that most farmers still conceive of environmental protection as a matter of excessive cost to comply with certain regulations. Only a minority are making a transition to a modern view in which environmental protection is seen as a source of competitive advantage. Table 8 presents the changing international approaches to environmental management. Only Mexican producers of high-value export crops are adopting the modern approach, while farmers producing basic and traditional crops still adhere to the conceptions of the 1970s. The latter account for 90 per cent of the cultivated area and about 50 per cent of the value of output.

Table 8. **International approaches to environmental management**

1970s	1980s	1990s
Cleaning up polluted areas	Protection of human health	Preventing generation of contaminants
Compliance with regulations	Risk management	Prevention
Motivated by legislation	Motivated by awareness of environmental problems	Motivated by creating competitive advantages

IV. BIOTECHNOLOGY IN MEXICO

Biotechnology offers the promise of solving many critical agricultural problems and the potential for sustainable production. From a global perspective, however, biotechnology's development is almost exclusively concentrated in highly industrialised countries, which is not surprising in light of the high-level scientific research and the capital it embodies. Moreover, innovation is increasingly controlled by large multinational companies (see Table 9).

Table 9. **Anticipated applications of agricultural biotechnology**
(Selected products)

Product/Attribute	Companies	Year reaching market
Tomato Spoilage retardant	Calgene, ICI,Monsanto, DNAP, Agritope	1993
Bovine growth hormone Increased milk production	Monsanto	
Food oils Increased saturate levels, cheaper substitute for cocoa butter	Calgene, Dupont, DNAP, Pioneer	1994
Cotton Bromoxynil tolerance	Calgene	
Corn (Maize) Insect, disease, and herbicide resistance	De Kalb, Ciba-Geigy, Pioneer, Monsanto, Cargill, Upjohn	1995
Raspberries Increased shelf life	Agritope	1996
Potato Virus resistance	Calgene	
Tomato Pest resistance	Agrigentics, Campbell	1997
Tomato Virus resistance, fungus resistance	Agracetus, Asgrow/Upjohn, DNAP	1999
Potato Altered starch to improve frying	Monsanto, Frito-Lay	
Transgenic wheat Drought resistance	Monsanto	2002

Source: Ernst & Young, 1993.

It is paradoxical, however, that developing countries could be the main beneficiaries of agricultural biotechnology. Indeed, it is expected that in the current decade biotechnology will be used in the following areas (Thomas, 1992):

— Production of new varieties of plants,
— Biopesticides,
— Diagnosis of plant and animal diseases,
— Growth hormones for animals,
— In-vivo micro-organisms,
— Transgenic animals.

Given these applications, it would appear that the future of agriculture, in large measure, will depend how well countries can select, acquire, adapt, develop and diffuse new products and processes based on biotechnologies. This capability, in turn, largely depends on the scientific and technological capabilities, entrepreneurial skills and public policies which promote the development and diffusion of the new biotechnologies.

This section analyzes Mexico's biotechnology policies, emphasizing biotechnology developments, and the incentives and constraints affecting biotechnology in the agricultural sector. In short, the competitiveness of Mexican biotechnology is evaluated, with the objective of identifying strengths and weaknesses, as well as providing useful information for future policies.

Early Policies Relevant to Biotechnology

Although Mexico has explicitly recognised the value of biotechnology for attaining sustainable development, this has not been translated into a concrete scientific and technological policy. Indeed, technological innovation is still limited and disparate, not part of any long-term strategy. Thus to date, scientific and technological policy has not been a central agent in Mexico's structural change (OECD, 1994).

The first official science and technology policy was defined in 1976 but was only in force for two years. Then in 1978, the National Indicative Programme for Science and Technology was drawn up and remained in force until 1982. Both policies tried to define priorities. Agriculture and agroindustry were both stressed although biotechnology was not explicitly mentioned.

In the early 1980s, the country was confronted with the importance of having a national strategy for biotechnology for the first time. Mexico had the opportunity of becoming the host country for the International Centre for Genetic Engineering but lost the chance, to a large extent, due to lack of clear long-term objectives (Quintero, 1994).

In 1984, the National Programme for Technological and Scientific Development (PRONDETYC) for governing research was established, and remained in existence until 1988. PRONDETYC established explicit guidelines for biotechnological development related to national priorities, including agroindustry, nutrition and health. For biotechnology, the PRONDETYC established specific priority research lines which included:

— Use of agricultural produce and forestry waste products for animal food.
— Studies on the biodegradation of lignocellulose waste.
— Development of biotechnologies like genetic engineering, tissue culture and enzyme engineering.
— Bioengineering support.
— Unicellular protein production.
— Better use of sugar cane and its by-products.

In concrete terms, biotechnological policy then consisted of support for its development, by strengthening research and the industrial applications on the one hand, and by establishing networks between different institutions that would permit them to work in specific technical areas and co-ordinate their work on developing biotechnology products, on the other

Private sector participation was encouraged by soft credits for technological development from the Bank of Mexico's Industrial Equipment Fund and the Shared Risk Programme Fund of the National Council for Science and Technology (CONACYT). The fruits of this policy were rather modest, mainly because investment in research fell drastically from more than 0.5 per cent of GDP in 1982 to 0.16 per cent in 1988. Furthermore, biotechnology had no explicit objectives and was simply incorporated into the work of the principal researchers at that time. Nevertheless, it was possible to strengthen important centres that are now the basis of the country's research capability in biotechnology.

Current Biotechnology Policies

After the sharp fall in expenditure on research during the "lost decade" of the 1980s, the present administration launched the National Programme for Science and Technological Modernization. In brief, the Programme aims at promoting scientific achievements that meet international standards. In technology, the aim is to increase productivity, strengthen competitiveness and favour technology that will preserve the ecological environment and make optimum use of natural resources.

Under this programme, it has become apparent that the government is supporting scientific development and leaving responsibility for technological modernization to the private sector. This could be considered the best course of action if Mexican firms were sufficiently mature to recognise the importance of innovation for competitiveness. Unfortunately, this is true of only a few firms, and the policy makers' belief that expectations of commercial rewards would be a sufficient incentive to stimulate the innovative spirit has not materialised.

However, there have been some major achievements in science. Mexico has obtained financing from the World Bank for the Scientific Support Programme (PACIME), which is primarily for scientific training, research projects and the creation of infrastructure. The "new" CONACYT, as it is now called, has established a series of mechanisms centred on peer review to promote high academic and technical standards in all the activities it supports. Among its main programmes are providing support for graduate courses, encouraging repatriation of Mexican scientists working abroad, providing grants for high-quality basic and applied research in all scientific areas, strengthening the country's industrial capability, and stimulating industrial innovation by assuming some of the risk, and more effectively linking research to private industry (Eastmond *et al.*, 1992).

The establishment of priority areas is not contemplated and the criterion of excellence is the only one being followed for supporting projects. Supply and demand mechanisms, combined with academic evaluations (both of the research group and the proposal), have been established as the main means for selection in basic and applied research. There is no policy or programme specifically dedicated to the promotion of biotechnology.

This unwillingness to define priorities, or even to identify opportunity areas, may have developed after past unsuccessful experiences in which the priority-setting exercises were not used as the starting point in formulating policies (Solleiro, 1994). Although the idea of developing a National Biotechnology Plan has been examined from a scientific, political and industrial standpoint, it has not led to significant changes in the national policy.

However, biotechnology has spontaneously received special treatment because of scientific demand in this area. According to CONACYT figures, the Council allocated 17.2 per cent of its resources to biotechnology research projects in 1991. In 1992, 12.2 per cent of its budget went to biotechnology but the absolute sum was greater (4.382 billion pesos in 1991 as opposed to 7.711 billion pesos in 1992). Thus in 1992, approximately $2.5 million was channelled into biotechnology projects. In 1991, CONACYT allocated 17 per cent of its funds for infrastructure to biotechnology, and 6 per cent for this purpose in 1992.

There are no specific programmes for supporting biotechnology innovation, while support for firms that want to develop technology is limited to credit lines from the FIDETEC Trust, managed by CONACYT, and the National Financial Institution (NAFIN) and NAFIN's own Programme for Technological Development. These credit lines do not provide special interest rates, but they support the firm's guarantees. However, the two financial programmes must channel their resources through private banks. This makes negotiating a credit a real nightmare. Very few firms can satisfy the requirements imposed by the banks. Even though FIDETEC and NAFIN provide guarantees, the banks increase their demands in case there has been a loss and this drives the firms away. Thus during the past five years, only a few dozen technological development projects in all areas have been supported by these programmes.

In 1990, the Science Consultative Council of the President's Office recommended the establishment of a biotechnology programme in which priority sectors would be defined, and projects of national interest and viable technological development projects would be identified. To be exact, 15 projects of national interest were proposed, two corresponding to the agricultural sector and one in forestry. It was hoped that they would give rise to concrete initiatives that would represent an opportunity for the industrial sector. Although these recommendations have not been put into practice, it is perhaps worth mentioning that the proposals included a comprehensive research project to improve the cultivation of beans, a programme for biological control of pests in vegetables and fruit, and another concerned with reforestation.

The National Programme for the Modernization of the Countryside contemplated restructuring agricultural research to achieve a closer relationship between research and the extension services, with a strong component for efficient adaptation, assimilation and diffusion of technologies based on a system of economic stimuli. The development of biotechnology research with the participation of the private sector was also considered.

On the whole, these objectives have been confined to good intentions as agricultural research suffers from structural problems, the serious economic crisis and a lack of participation by the private sector. Just to illustrate this situation, it is worth mentioning that the Federal government's expenditure on science and technology has been decreasing during the last five years, declining from $95 million in 1989 to $70 million in 1993 (CONACYT, 1994). Moreover, the National Institute for Agriculture, Livestock and Forestry Research (INIFAP) has budgeted only about $15 000 for its Project 543 for introducing biotechnology to conventional plant breeding, which includes 15 projects for different crops (INIFAP, 1994). Thus it is difficult to foresee sound results unless private sector participation increases significantly.

Moreover, Mexican industrial policy has not considered bioindustries as a special objective. That coincides with a sort of indifference by financial institutions towards the creation of biotechnology-based enterprises (Quintero, 1994).

There are in Mexico some incipient programmes to support new technology-based ventures such as incubator facilities and technology parks, with the objective of helping new high-technology businesses by giving them access to facilities as well as managerial and financial support, but they are unspecialised, and one of their main weaknesses is that they are not well funded and there is no venture capital instrument for start-ups. Thus the climate for modern biotechnology companies is not very supportive.

In summary, Mexico does not have a specific biotechnology strategy and this has resulted in very uneven development dominated by academic achievements. Biotechnology industries are small and their growth has been very slow, in part, because there is no support or guidance for specific goals, since the government has been reluctant to define development priorities.

Plant Biotechnology in Mexico

Under the policy framework outlined above, biotechnology research and development in the agricultural sector has been difficult. There have been some major achievements in public institutions, but very little has been accomplished in the commercial application of biotechnology. The most successful companies that have incorporated biotechnology are well-established seed potato businesses and nurseries using micropropagation techniques (Eastmond *et al.*, 1992). An analysis of the potential of the different applications of biotechnology follows.

Tissue Culture

Tissue culture is the most widely used application of biotechnology in Mexico. Many universities and public research and development institutions possess facilities to apply this technique (though many of them work only in mushroom culture). There are also some private companies that have invested in commercial micropropagation (see Table 10). All of them still operate on a relatively small scale but have the capacity to augment production as demand increases. According to Lozoya (1992), there have been four different types of investors in the micropropagation business in Mexico:

— Capitalists who invest in biotechnology, supporting scientists who do not have experience in running commercial enterprises. In most of these cases, the lack of short-term profits has made them abandon the venture.

— Scientists who create spin-off companies. Most of them abandon the endeavour because of a lack of business experience and insufficient external support.

— Public institutions and programmes which have supported tissue culture projects for different crops without a long-term perspective. Examples of these institutions are the Mexican Coffee Institute (INMECAFE), the Comisión National del Maguey (National Agave Commission) and the Comisión National de Fruticultura (National Fruit Farming Commission). By and large, these institutions have not followed up their research to insure there was a commercial application.

— Well-established agricultural businesses (nurseries, seed companies and dealers in agrochemicals) which have made modest investments in new micropropagation facilities. These enterprises have been successful as a result of their previous experience, their political and business contacts, and the foundation on which they began the new business. The key to success has been that "before using biotechnology, they had plant or agricultural input businesses" (Lozoya, 1992).

Table 10. **Principal Mexican Firms with Plant Tissue Culture Laboratories (1992)**

Firm Private/ Public	Location	Species	Total Annual Production of Micro-Propagated Plants	Investment in Tissue Culture Lab (US$)	No. of Employees in Lab	Market % National	Market % International	In-House Research	Links With Public Research Centres	Future Plans
Biogenica Mexicana, S.A. C.V. (private)	Office in Mexico City, labs in Michoacan	Gerbera Gyposophyla Dieffenbachia Caladium Agave Spatiphyllum Singonium Anturio Woody Species	3,000,000	400,000	25	50	50	Technology adaptation	CICY UNAM	
El Rancho La Joya (Private)	Offices and lab in Alixco, Puebla	Orchids	100,000	100,000	3	20	80	No	No	Micro-propagate other species such as roses for export
Gota De Vita (private)	Huitzilac, Morelos	Potato				Internal use only		No		
Invernamex (private)	Office and lab in Tepotzotlan, Mexico State	Gerbera Gyposhyla Strawberry Raspberry Potato Banana Pineapple	3,000,000	500,000	25	100		Technology adaptation	UACH	Go into export market
Rancho Providencia	Toluca, Mexico State	Potato		150,000	7	Internal use only		No	UACH	
Viveros El Morro (private)	Mexico City	Spatyphyllum Singonium	300,000							
Vivi Toluca (private)	Toluca Valley	Potato				Internal use only			INIFAP	
Fira (public Bank of Mexico)	Tezoyluca, Morelos	African violet Gerbera Chrisanthemum Strawberry	100,000	45,000	7	100		Yes	UAC	Transfer micro-propagation methodologies to small producers

Source: Eastmond et al., 1992.

The main limiting factor for these companies is effective demand. Companies engaged in micropropagation of ornamental plants can be competitive, because their production costs are substantially lower than those in America and Europe. But in most cases, there is still no export market because they do not meet quality requirements. None of the companies listed in Table 10 has the research capability for improving quality and creating new products. Some of them have taken the initiative to collaborate with research institutions, but they are unusually unwilling to pay the real cost of research (Eastmond, 1992). There are some successful examples of technology transfer from research institutions, two of which are mentioned in Section V.

Commercial Biopesticides

The biological control of agricultural pests has been increasing throughout the world. Since biotechnology began to be used in Mexican agricultural research in 1983, it has been considered possible to make greater use of live organisms and/or their metabolic products against crop pests. Some of these biopesticides have been in commercial used for more than 30 years in developed countries, but in developing countries their use is still quite limited.

The U.S. market for biopesticides derived from bacteria, fungi, viruses and pheromones in 1990 was $107 million. The most important products in terms of volume and sales were those derived from the bacteria *Bacillus thuringiensis*. The world market for products derived from *Bacillus thuringiensis*, estimated at $105 million in 1990, is dominated by three large international corporations (Abbott, Monsanto and Sandoz). Five years ago, 15 companies, specializing in biotechnology and crop-protection chemicals, formed the *Bacillus thuringiensis* Management Working Group to address research problems that confounded all advocates of *Bacillus thuringiensis* (Kidd, 1994). Three biotechnology firms have recently started up in this area, Mycogen, Ecoscience and Crop Genetics, and gained approval for their products in 1993 (Burril and Lee Jr., 1993).

Even though the concept of biopesticides is not new, it is still in the experimental stage. Growth has been largely spurred by the search for less polluting agrochemicals, but relatively few products have been commercialised to date. The principal biopesticides are described below:

Product Pests to be Controlled

Bacteria	
Bacillus thuringiensis	Lepidoptera, mosquitoes, coleoptera
Bacillus popillae	Coleoptera
Pseudomonas fluorescens	Phyuthium (wheat fungus)
Streptomyces (bialophos)	Weeds and grasses
Agrobacerium radiobacter	Agrobacterium tumefaciens
Recombinant Agrobacterium tumefaciens	Agrobacterium tumefaciens
Pseudomonas fluorescens	Pseudomonas tolaasii (edible mushrooms)
Recombinant Pseudonomas syringae	Pseudomonas syringae and Pseudomonas fluorescens (strawberry, potato)
Fungi	
Beauveria bassiana	Coleoptera (potato)
Hirsutella thomposonii	Acari (citrus fruit)
Metarhizium anisopliae	Hoppers (sugar cane)
Verticullium lecanii	Aphids
Verticillium lecanii	White fly
Collectrotrichum gleosporioides	Weeds (rice, soy beans, beans)
Phyophtora palmivera	Weeds (citrus fruit)
Alternativa cassiae	Weeds (soy beans, peanuts)
Colletrotrichum coccodes	Weeds (maize, soy beans)
Insects	
Epidinocarsis lopezi (bee)	Insects that attack the
Cactoblactus	Weeds
Various insects	Weeds
Viruses	
Cydia GC	Insects
Heliothis NPV	Insects (cotton)
Lymantria NPV	Insects
Neodiprion NPV	Insects (pine)
Mamestra NPV	Insects (cabbage)
Protozoa	Nosema locustaeLocust
Nematodes	
Heterorhabditis heliothidis Steinemema sp	Insects (ornamental plants) Various insects

Transgenic plants present another approach to using biotechnology against crop pests. More than 60 different crop plants have been genetically transformed, usually by introducing some gene that gives them resistance to insects, viruses or weed-killers, and it is soon expected to be able to obtain resistance to fungi. Commercialization of transgenic plants has been relatively slow, since in many industrialised countries consumer groups have questioned their safety.

In Mexico, the use of insects and sterile flies for the biological control of pests has been widely diffused by public institutions. In the case of new biotechnology research, must of the groups that are carrying out research into biopesticides are working on *Bacillus thuringiensis*, but another small group is working on transgenic plants. Work on other biopesticides is dispersed and lacks direction. Table 11 summarises the work of the principal groups.

Table 11. Mexican biopesticide research

Institution	Group leader	Research line[1]
UNAM: Biotechnology Institute	Alendra Bravo Rodolfo Quintero	* Bt: action mode of the 6 toxin isolation and selection of endotoxins * Production of bioinsecticides for specific pests
Autonomous University of Nuevo Leon	Luis Galán Benito Pereira	* Molecular biology of Bt * Fermentation technology and scaling of the bioinsecticide production * Strain bank (4000)
Autonomous University of Nuevo Leon	Cristina Rodríguez Reyes Tamez	* Isolation and classification of Bt Mexico
Center for Research and Advanced Studies (CINVESTAV), D.F	Mayra de la Torre Bernardo Flores Raúl Urquijo	* Fermentation processes and pilot production of bioinsecticide * Feasibility studiesTechnological Institute of DurangoHiram Medrano* Fermentation processes at a semi-pilot scale and field trials
Autonomous University of the State of Morelos	Eduardo Aranda Guadalupe Peña Armando Burgos	* Isolation of new strains of Bt
CIMMYT	Natasha Boborova David Huisington	* Evaluation by means of field trials and bioassay of commercial formulations of Bt
CINVESTAV -Irapuato	Jorge Ibarra	* Isolation of native strains of Bt to be used against specific pests * Large collection of strains
Autonomous University of San Luis Potosi	Norma Saavedra Ovidio Díaz Luis Antonio Castanón	* Evaluation by means of field trials and bioassay of commercial formulations of Bt

Table 11. continued.

Alimentos del Fuerte,S.A	Cosme Cruz Gregorio Aceces	* Experimental and semi-commercial test with commercial formulations
Autonomous University of San Luis Potosi	Carlos Villar Andrés Delgadillo Gerardo Hernández	* Control of the maize worm, spodopetera fragiperda with solutions
University of Sonora	José Javera Héctor Jasso	* Use of insects to control aphids
Postgraduate College	Raquel Alatorre Jorge Valdéz	* Bioassays for the use of fungi against acari
Autonomous University of Guerrero	José Luis Rosas Yolanda Rosas Andel Sánchez	* Use of fungi against white fly
INIFAP	María Jarillo Ramón Rodríguez	* Use of the wasp against eggs of the Mexican Oebalus in sorghum * Fight against the pink worm with Trichogramma toidea bactrae
Zeneca Mexicana,S.A.	Baldomero Huerta	* Use of plant extracts to control viruses in tomatoesCINVESTAV - IrapuatoAlfredo Herrera Luis Herrera Estrella* Isolation of fungi as bioinsectides * Obtaining of transgenic plants - Virus resistant potato - Virus and lepidoptera resistant tobacco - Virus resistant asparagus - Virus resistant chile - Virus resistant tomato - Lepidoptera resistant maize * Control of fruit ripening

1. Bt = Bacillus thuringiensis

It can seen that there are five strong institutions working on *Bacillus thuringiensis,* with a small number of researchers with doctorates and/or M.Sc. degrees (Quintero, 1994).

CINVESTAV-Irapuato has the only consolidated group of international standing doing research into transgenic plants, of which 14 members have doctorates and six have a M.Sc. The Biotechnology Institute of the UNAM does basic research on aspects of vegetable biotechnology. Annual funding for plant genetic engineering by the CINVESTAV group is about $1.5 million, and that by the UNAM group is around $400 000.

It is rather surprising that the agricultural research institutions of long standing are only beginning biotechnology work. Few private firms do evaluations or carry out field tests. In brief, there is relatively little work being done on developing biopesticides, or on transgenic plants resistant to agrochemicals and pests, and what exists is far from ready for commercial use, although some of the research groups have a good basic knowledge of the field.

Biofertilisers

Relatively simple biotechnology is being used by nurseries which have found that soil from forests improves the quality of plants. It has been ascertained that this is due to mycorrhizas in the soil. Nonetheless, only four research groups are systematically studying the potential use of mycorrhizas, not only for nurseries but also for vegetables, flowers and other crops. All these groups are located at public institutions: CINVESTAV-Mexico City, Colegio de Posgraduados (Postgraduate College for Agricultural Science), INIFAP and UAM-Xochimilco (Metropolitan Autonomous University in Mexico City). Most of the research workers are making field trials in collaboration with farmers, but there do not appear to be any commercial applications.

Producers also widely use composting and worms for soil improvement. These techniques has been promoted by associations linked to the marketing of products derived from the organic agriculture. Organic farmers produce for U.S. and European customers with very rigid quality specifications. Marketing organizations supervise production and provide technical assistance, supported by inspection manuals. The use of microorganisms for nitrogen fixation and composting techniques are recommended. It is clear that the market demand has been useful for the diffusion of these biotechnologies among this segment of producers.

The most important agricultural and biotechnology research centres have groups working on biofertilisers derived from rhizobium. Some results are already available but their transfer to production has been difficult.

One major factor limiting the use of nitrogen fixation agents is that very little investment has been made in product validation. Among the few companies introducing new biofertilisers on the Mexican market are PROQUISA (Productos Químicos de Chihuahua, S.A.), Agricultural Regional, S.A. and Química Lucava, S.A.

These companies have confronted a series of problems relating to their new products. The first two companies have developed their own technologies to produce "Promesol" and "Biofer" respectively. Both companies are critical of the lack of infrastructure and organization for technical assistance, as well as for field trials to validate their products. The cost of this stage of product development is very high and is more than the firms can afford.

Lucava, a chemical company which used to be a subsidiary of Stauffer Chemical Co., has had almost 30 years of experience selling agrochemicals in the Mexican market and abroad. It only has one biotechnology product, an inoculant of rhizobium applied to soy bean seeds. Lucava asserts that the rhizobium is profitable but the market is still very small. It considers the main obstacle as cultural, the farmers' reluctance to use new products. Moreover, the decrease in extension work also contributes to the market's very slow growth.

Competitiveness of Mexican Biotechnology

The potential for the development of Mexican biotechnology in the international markets is based on an analysis of a series of critical variables for competitiveness, according to the system used by the Office of Technology Assessment (OTA) of the United States. Under this methodology, the first step is to consider the level of industrial activity and the number and type of firms that commercialise biotechnologies. The second step is to derive a general picture of competitiveness by evaluating ten factors that determine the future ability of a country to commercialise biotechnologies. These factors are:

— Government financing of basic and applied research.
— Availability and training of personnel.
— Financing and tax incentive for companies.
— Environmental regulations concerning health and safety.
— Protection of intellectual property rights.
— University-industry relations.
— Biotechnology policies.
— International flow of technology, investment and commerce.
— Anti-monopoly laws.
— Public perception.

It is also recommended to take into account the historical patterns of commercialization in the industry, availability of natural resources and entrepreneurial attitudes towards risk (OTA, 1991).

Using this framework, the results of different surveys, seminars, statistics, data bases, and case studies on firms, research and development canters and concrete projects were synthesised (Solleiro *et al.*, 1993). In Mexico, the first generation biotechnology industry has the largest market share. First generation biotechnology uses traditional biological processes. The main products of this industry in Mexico are fermented beverages, milk products, bread yeasts, alcohol and edible mushrooms. The companies concerned are basically oriented towards the domestic market (with the exception of beer companies) and do little R&D. Some firms also use second generation biotechnology, using advanced fermentation techniques and cell cultures for producing antibiotics, amino acids, organic acids and biofertilisers (some of the latter were already mentioned).

However, very few firms use the new biotechnology, involving transgenic organisms and recombinant DNA techniques. A relatively recent survey sponsored by IICA found that about 34 firms use some biotechnology (IICA, 1992). Most of them are less than 25 years old.

Most of the firms are small or medium-sized. Only eight of the 500 largest companies in Mexico use biotechnology. The majority of these companies are beer or alcoholic beverages producers, one firm uses tissue culture for the production of natural pigments, but none of them use the new biotechnology. We have found that the ability of domestic firms to develop new processes is limited, since only a very small number (approximately 27) invest a fairly significant amount (at least $2 million a year) in R&D. A study of six innovative biotechnological firms (Solleiro *et al.*, 1992b) shows that these firms tended to enter only in the last stages of the product's life cycle, and did not readily anticipate changes. We have also observed that, with some exceptions, Mexican firms tend to avoid alliances and co-operative projects. Indeed, the capital of 75 per cent of the firms that took part in IICA's survey was 100 per cent Mexican.

Most of these companies also operate in small and specialised niche markets. Their competitiveness is mainly based on the quality of their products. In the case of micropropagation companies, the advantages are phytosanitary guarantees, genetic homogeneity and large-scale supply potential (Jaffé, 1994). But these advantages are rather tenuous as most of the companies are too small to develop innovations which would increase their competitiveness. As already mentioned, the companies also are limited by a financial climate that is not very supportive of innovation.

By contrast, in the United States, the world leader in biotechnology, an average of 75 firms using new biotechnology are created every year. At present, there are about 1 100 U.S. biotechnology firms. More than 70 large corporations have begun to invest significantly in biotechnology. Sales are increasing, and R&D is no longer the only requirement for growth of a biotechnology firm. Managerial skills, an ability to negotiate the approval of new products, and strategic alliances are just as important as R&D. (Burrill and Lee Jr., 1991).

Of course, it is unrealistic to compare Mexico with the United States, but a comparison with countries like South Korea, Brazil, Spain and Canada still suggests that the biotechnology industry in Mexico is lagging.

Next we try to provide a more objective assessment of Mexican biotechnology in terms of the ten factors for evaluating technology:

Government financing of R&D

As mentioned, some preferential support has been given to biotechnology in recent years. Nonetheless financing is still very low. For example, CONACYT provided a little over $2 million to biotechnology projects in 33 institutions in 1991 (CONACYT, 1991). This suggests how little support each project receives. Much more funding is given to basic research than applied research. This is because the Federal government considers that the private sector should be responsible for applied research. However, there are very few private sector research projects, and even fewer have obtained support from government funds for encouraging industry.

Availability and training of personnel

Although some analysts state the contrary, we believe that there are still very few personnel available for the biotechnology research. In 1992, the National System of Researchers (SNI) as a whole had just over 6 500 members. In the areas related to biotechnology (agronomy, biology, health sciences, pharmacy, industrial engineering, chemical engineering, medicine, veterinary medicine, chemistry and zoology) there are slightly more than 2 500 researchers. Although there are no precise statistics, we can state that only a small proportion of these researchers do biotechnology work. For example, only 14 researchers affiliated with the National Institute for Agriculture, Livestock and Forestry Research (INIFAP) do biotechnology work in all of Mexico. Concerning the training of human resources, almost 40 per cent of graduate students are in a field of medicine. Most graduate students are receiving specialised training or working for a master's degree. In all fields of study combined (i.e. arts, social sciences, medicine, engineering, sciences, etc.), 4 525 specialists, 5 091 master's degree students and 269 PhD students graduated in 1991 (Reyes-García, 1992). However one interprets those figures, it would appear that there are few job openings for persons qualified in biotechnology: industry would find it difficult to absorb them and public research institutions have instructions not to expand.

Financing and tax incentives for enterprises

In Mexico today, it is difficult to finance industry of any type. The rate of interest on industrial credit is five to six times greater in real terms than in developed countries. There are no special programmes for financing industrial biotechnology projects or for providing venture capital. Furthermore, there are no tax incentives for biotechnology enterprises. In contrast, Taiwan decided that biotechnology should be one of its four strategic industries and set the goal of obtaining 2 per cent of the world market by the year 2000. For this purpose government banks are providing venture capital for new companies. The government also established special tax exemptions for biotechnology. Thus from 1986 to 1990, 13 Taiwan companies were established with venture capital and the number of biotechnology firms continues to grow.

Environmental, health and safety regulations

As mentioned, Mexico has made major efforts to establish a suitable regulatory framework. For example, it now has modern laws governing pollution control, sanitary regulation, regulation of research in health, etc.

Following international recommendations, Mexico created a National Biosafety Committee with the aim of making decisions about the release of genetically modified organisms in the environment. The Committee is comprised of leading scientists, Ministry of Agriculture and Hydraulic Resources (SARH) officials and representatives of producers. It works on a case-by-case basis, focusing on the characteristics and possible risks of the biotechnology product, not the process by which it is created.

The Committee has also been developing procedures to govern the use of biotechnologies. It issued an official standard for regulating the release of transgenic plants for field testing.

However, there is still much work to be done. Following the framework proposed by ISNAR (Persley *et al.*, 1993), Mexico still has to incorporate biosafety requirements into the overall regulatory system and to establish guidelines for both physical and biological containment and/or control procedures appropriate to risks in research, production and applications.

Furthermore, considerable training of personnel with regard to safety procedures is needed. If the number of biotechnology applications grows significantly the review process will lack sufficient human resources. This is already the case in the Ministry of Health body responsible for the approval of product licenses. Another problem is the lack awareness of the regulations on biotechnology in the regulatory system and in the society at large. This could become a major impediment to obtaining capital and technology by new firms, as well as to forming international alliances in biotechnology.

Protection of intellectual property rights

Protecting intellectual property rights (IPR) for innovations has become a basic objective of companies seeking to commercialise biotechnology. This renewed interest in IPR has already triggered unilateral actions, such as those undertaken under the U.S. Trade and Tariffs Act as well as multilateral negotiations within the World Intellectual Property Organization and the GATT (Correa, 1993). Intellectual property rights played an important role in the NAFTA negotiations.

In June 1991, a new Mexican law for the Promotion and Protection of industrial Property was approved. It opens up the possibility of patenting most inventions related to biotechnology, such as new plant varieties, biotechnology products and processes, microorganisms and the processes in which they take part, all kind of agrochemicals, and pharmaceutical products.

This brought some peace of mind to those who had pressured for change and who believe that patentability is a prerequisite to the flow of foreign technology and investment in those areas. However, three years later, uncertainty again reigns, since there are still no regulations for enforcing the law. Nonetheless, we are convinced that the legal framework for protecting biotechnology will soon be completed. In fact, a reform of the 1991 law was approved on 2 August 1994, granting broader protection to biotechnological inventions, including patent protection for transgenic animals. The reform states that plant varieties will be protected by plant breeders' rights. It is expected that new legislation for the protection of plant breeders' rights will be introduced in the near future. A draft has already been drawn up and it follows the model of the UPOV Act of 1991.

Despite this progress, it will be difficult to enforce any legislation. Mexico lacks the institutions and the qualified personnel for safeguarding intellectual property rights, Moreover, under present conditions such protection will not promote domestic innovation, but will mainly benefit foreign firms wanting to protect an export monopoly and not necessarily interested in manufacturing biotechnological products in Mexico. A review of the official journals on inventions and trade marks over the last two years revealed that only 65 of the 3 100 applications for biotechnology patents at the Mexican Patent Office (Instituto Mexicano de la Propiedad Industrial) between 1991 and March 1994 involved Mexican research.

University-industry relations

Co-operation in Mexico between universities and industry in biotechnology is still in its infancy. However, university laboratories have already developed some techniques for firms under research contracts.

Some of these agreements deal with biotechnology for agriculture, especially tissue culture techniques. For example, the Colegio de Posgraduados did work under an agreement with Sabritas (Pepsico) on the development of specific varieties of potato for snacks; the Scientific Research Center of Yucatán (CICY) has been working with a large Mexican company to develop new varieties of flowers for the extraction of colouring matter; and CINVESTAV-Irapuato is currently engaged in a research project for the Bajio Vegetable Producer Association (El Bajio is an important agricultural region in central Mexico).

However, very few projects or this sort have resulted in a product or process suitable for commercial exploitation. This feeds scepticism and mutual distrust. Improved relations between academic research groups and the productive sector will require better management, but only a few universities have created technology transfer or liaison offices to foster collaboration with the potential users of research results. Mexico's science and technology policy creates another hurdle by emphasizing pure research, which discourages collaboration with industrial firms.

Biotechnology policies

As mentioned, biotechnology research receives more resources than other areas, but there are no priorities. Each project is funded on its own merits. Other countries have made an effort to promote research in areas that could help enhance its competitive advantages. At present, Mexico tends to adopt biotechnology late in its life cycle. The practical effect of this is that very few firms are interested in the results of research (Solleiro *et al.*, 1992a).

International flows of technology, investment and trade

Even though there has been an important increase in foreign investment in Mexico, it is mainly concentrated in marketing and speculation. Mexican firms need to develop their technical excellence, knowledge of the market, and access to international markets to attract more investment for productive activities.

Anti-monopoly law

Biotechnology products can have significant implications for the social welfare of the population, and the biotechnology industry in advanced countries tends to grow by means of industrial alliances. This has led to concern about the need for effective anti-monopoly laws. Mexico is still at the stage of formulating an anti-monopoly law.

Public perception

The attitude of the public at large to biotechnology can affect its development. In Germany, for example, the concerns of ecology groups have added to R&D costs and reduced competitiveness, despite the country's advanced research capabilities. However, thus far Mexico has not been concerned about domestic public opinion on biotechnology issues.

This brief analysis suggest that Mexican biotechnology is on the whole less competitive than other newly industrialised countries. There are strengths such as the existence of some R&D institutions with experienced researchers, which could serve as a basis for the growth. There have also been important advances in providing a modern legal framework. However, this new framework does not yet cover biotechnology. Finally, the country has an open, relatively stable economy suitable for investment and the introduction of new technology.

In brief, there is neither a public strategy for the development of biotechnology nor a vigorous biotechnology industry which could provide momentum.The research base is small, fragmented and, on the whole, detached from commercial applications. Few highly qualified personnel are being trained and there is little incentive for making a career in biotechnology research. Funding for research is inadequate, and such as it is, mainly goes to basic research. Finally, the "biotechnology community" of academics, entrepreneurs, public officials and users of biotechnology is not accustomed to collaboration, and this limits the scope of possible accomplishment.

V. FACTORS INFLUENCING THE DIFFUSION OF BIOTECHNOLOGIES

As has been made clear, there is ample need for biotechnology to promote agricultural development in Mexico. Biotechnology's ability to "design" plants for specific requirements is especially of interest to Mexican farmers (Eastmond, 1992). There is a pressing need for plant varieties that can adapt to unfavourable environmental conditions such as saline soils, drought, and high temperatures, and of course, with enhanced resistance to pests and disease. There is a vast potential for biotechnology in a country like Mexico, in which only 15 per cent of its territory is arable using conventional technology, and 53 per cent of the fertile land is in arid and semi-arid zones, which require irrigation and are highly susceptible to salination. Although the country has the research facilities and human resources that could serve as a starting point for applying biotechnology to these problems, very little has yet been done at the practical level.

Indeed, a search of literature revealed no specific works which evaluated biotechnology in agriculture or its acceptance by agricultural producers. Interviews with agronomists, researchers and producers revealed very little familiarity with the subject. Only some rudimentary biotechnology is used widely, although in a rather empirical way, as with mycorrhizas in nurseries. We will now analyze the factors influencing the diffusion of biotechnology in Mexico.

To be sure, there have some successful cases of research and technology transfer in the field of micropropagation. The most important of these involved the Scientific Research Center of Yucatán (CICY) and FIRA's Training and Demonstration Center of in Tezoyuca, Morelos.

CICY propagated the tequila agave (*Agave tequilana*), working under contract with tequila producing firms which had requested support when serious crop problems threatened their competitiveness. Plant diseases and the slow crop growth (eight years before commercial exploitation) put tequila firms at a disadvantage with in relation to the producers of other alcoholic beverages. CICY developed a technique for producing healthy plants that provided greater yields under a contract with a private company. However, transferring the technology from laboratory to commercial use was very difficult, The original firm withdrew its support, but a second company provided support for continuing with the project. But this firm too was unable to assimilate the technology, and finally it was necessary to find a small micropropagation firm which had sufficient skill to use the technology and become a supplier of plants for commercial use. Even though mistakes were made in the management of intellectual property rights and in the research agreement, the three essential actors were a highly qualified research group, a private company with the skills for using the new technology, and an end user with an explicit demand for the product (the micropropagated plants).

The FIRA Center is a tissue culture laboratory created in 1988, which has given courses to technicians and producers on these techniques since 1990. It was able to adapt the technique for use with limited resources and provide training in laboratory techniques and for the handling the plants in a greenhouse. Furthermore, since FIRA is a credit institution, it provides financial support for producers in the form of a package which includes credit for building a small tissue-culture laboratory, technical assistance as long it is needed, and material for beginning production.

It can easily be seen that the keys to diffusing these techniques have been the technical ability of the recipient (the producer) and technicians able to translate laboratory results into commercial products. Furthermore, the commitment of the financial institution has played a critical catalytic role.

Biotechnology, Farmers and Traditional Agricultural Research

In general, farmers and technicians who work in the field do not yet have a precise idea of what biotechnology is, much less its implications for agriculture. There are even branches of agriculture which are opposed to new biotechnology, *per se*. Curiously, this is true of "organic agriculture" producers' groups which are subject to very strict technical requirements by consumers. These producers are sceptical, and confused by the inspection regulations, and thus far have rejected the use of tissue culture and other new biotechnology.

When biotechnology was in its infancy in the 1970s and early 1980s, both researchers and agricultural extension workers took a sceptical view of it. The lack of resources for research only enhanced such attitudes among the agronomists. Biotechnology work has only recently begun in the main agricultural research institutes and has been primarily confined to tissue culture. In 1992, INIFAP, one of the biggest, most important research centres in the country, had only 14 researchers working on biotechnology with a budget of only $60 000 (Torres, 1992).

Six agricultural colleges very recently began teaching programmes in biotechnology, although they do little research and only have laboratories for tissue culture. There is virtually no academic work in fundamental areas such as molecular biology, biophysics and cellular biology. A survey of agrobiotechnology in Mexico (Solleiro and Quintero, 1993) concluded that a lack of human resources was one of the main factors limiting the development of this new scientific basis for agriculture. The main public institutions for agricultural education and research are now aware of the problems and are trying to build or strengthen laboratories with financial support from the Inter-American Development Bank.

The relationship between biotechnology and traditional agricultural research is still very tenuous. This creates an important barrier to the diffusion of technology which can only be overcome by encouraging interdisciplinary work by agronomists, plant breeders and biotechnologists. There are some promising initiatives like CINVESTAV-Irapuato's link with INIFAP's traditional plant breeders for improved training of biotechnology researchers for the country's other institutions (Maddox and Gee, 1994). However, there is still much to be done to develop closer relationships between biotechnologists and traditional plant breeders.

Moreover, improved training in molecular biology is needed in agricultural education. International co-operation can play an important role in supporting training programmes and the establishment of basic facilities for the new biotechnology.

The Role of Non-Governmental Organizations (NGOs)

In recent years, many non-governmental organizations have been working in different aspects of development. In some domains, NGOs have become essential complements of public institutions for promoting development, and even for the creation and diffusion of technologies.

In Mexico, there are more than 500 NGOs which work mainly in rural regions. Perhaps the most important of them is the Mexican Foundation for Rural Development. It has played a significant role delivering technical support to small farmers in many different regions of the country. This and other NGOs have been very effective in diffusing agricultural and environmental technologies. But it has not been possible to identify NGOs for which biotechnology is a priority in research or technical assistance. This can be explained by a number of factors (Kurzinger *et al.*, 1991):

- — Lack of professionalism in the NGOs.
- — Financial constraints.
- — Limited knowledge of biotechnology's potential.
- — Problems in making scientific information accessible to common people and in foreseeing tangible benefits from research.

These factors hinder the participation of NGOs in the diffusion of biotechnology, but this does not mean they are unimportant. There are NGOs such as producer associations which play a major role in improving farmers' access to biotechnology. In some crops, these associations even control the flow of technology to the farmer, for example, with strawberries. The Producers Union has an agreement with the suppliers of propagation material and distributes the strawberry plantlets to the farmers, who are not allowed to test other materials. Other associations promote technical change. For example, the Confederation of Farmers Associations of the State of Sinaloa (CAADES) established a private non-profit research foundation which assists members in identifying, selecting, negotiating for and using new technologies. CAADES organises study trips, sponsors applied research projects and disseminates technical information.

A major contribution to the diffusion of biotechnology is also made by organizations established by research groups and NGOs devoted to natural resource management. Both have technical abilities which can be used as a starting point for more productive relationships between researchers and the end users of biotechnology. It is evident that it would be mutually beneficial for research groups and biotechnology companies to establish closer links with producer associations and professional NGOs, to help their efforts to bring biotechnology to farmers.

The Role of the Extension System and Market Channels.

The agricultural extension system and the technical assistance programmes are other key elements in the diffusion of technology in agriculture. Agricultural extension in Mexico goes back to beginning of this century, but has been affected by political instability and frequent policy changes. By about 1954, extension had become concentrated in zones under irrigation and, for the first time, organised producers participated in its planning. Thus small farmers in the vast zones devoted to traditional agriculture no longer received any attention. During the 1960s, an effort was made to redress this neglect by expanding the network of experimental stations. As a result, and despite a lack of financial and human resources, there was a growth in agricultural extension, and in 1971 it was given General Office status with a staff of 1 583 within the Agricultural Ministry.

In 1977, the General Office was closed and the technical assistance activities were transferred to the irrigation districts and the seasonal agricultural districts. The next three years were marked by a period of anarchical growth and the number of extension workers attained 21 500, of whom 57 per cent were assigned to seasonal agricultural zones (Novelo, 1990). However, the technical competence of the extension services had noticeably decreased.

In 1982, a further reorganization occurred and these services were transferred to the newly established Rural Development Districts, administered by the state offices of the Ministry of Agriculture. Until 1990, technical assistance was provided in that way by 10 224 extension workers. At present, a new concept of extension service is under consideration. The idea is to transform extension workers into private agricultural consultants.

According to experts, it is not possible to meet the challenges posed by the modernization of agriculture with the existing extension service. On the one hand, if only the area sown with basic crops is considered, each extension worker would have to cover 2 575 hectares on average. On the other hand, the technical level of extension workers has been decreasing because of insufficient training and because their services are no longer based on ties with research institutions. Thus the extension workers cannot necessarily be counted on to inform the agricultural community about new biotechnology products.

However, if the extension service is privatised the more highly qualified extension workers will become agents promoting biotechnology among producers who can pay for their services. Small producers with few liquid resources would be unlikely to pay for the qualified extension services which could inform them of new biotechnology.

Another major factor affecting farmer acceptance of biotechnology involves dealers who inform farmers about the advantages of biotechnology products. According to a survey in Canada dealer service is major factor in farmer use of products for promoting plant growth, along with the reliability of company representatives and the information provided by extension workers (Klein *et al.*, 1994).

In Mexico, large multinational chemical companies have well-trained representatives who supply information to farmers on the use of new products. On the other hand, smaller companies cannot afford such representatives, and most small firms simply try to survive by concentrating their efforts in only a few segments of the potential market. Some of the companies approached for this study have attempted to sell through producer associations but without success. It appears that biotechnology companies will have to make greater efforts to keep extension agents aware of new product developments and also participate in the modernization of the extension system.

The Role of the Seed Industry in the Diffusion of Biotechnology

It is widely recognised that the production and commercialization of seeds and other material for plant reproduction play an essential role in the development and diffusion of technology in agriculture (Brenner, 1993). For this reason, we shall present a short analysis of the seed industry in Mexico and its relationship to technological innovation.

This industry's evolution has been closely linked with agricultural research. During the 1940s, Mexico began to develop a predominantly public system of research in this area. During the 1960s, two institutions were merged to form the National Institute for Agricultural Research (INIA), one of the model national canters of agricultural research founded in several Latin American countries, with technical and financial support from agencies and foundations in the United States.

In 1961, the National Seed Producer (PRONASE) was created and the government issued the first law regarding seeds, which was oriented towards public research on, production of and sale of seeds (López Pereira and García, 1994). For years the law gave PRONASE a virtual monopoly. Towards the end of the 1960s, some multinational companies began to introduce seeds to be tested in Mexico, although their market share was very small and grew slowly. At the beginning of the 1980s, demand for seeds increased substantially and sales of the industry's public and private branches increased, thanks to the Mexican Food System (SAM), a programme of mass subsidies to regain self-sufficiency in food.

However, this bonanza was poorly managed by PRONASE, which overproduced, accumulated enormous stocks, and almost went bankrupt at the end of 1982. Of course, this created a favourable opportunity for private industry. Moreover, the government's attitude towards the public seed industry shifted during the NAFTA negotiations in the late 1980s. In 1991, a new Law on the Production, Certification and Trade in Seeds was enacted. It facilitates private sector participation in seed development, production and commercialization. Private companies and individuals now will have a legal right to become seed certifiers, and responsibility for the quality of seeds marketed will be shared by the public and private sectors. This process of change has been accompanied by a drastic reduction in PRONASE's activities, and private industry has gained market leadership in crops like vegetables, sorghum, alfalfa, ornamentals and maize. A majority of the private sector's seed sales are by multinational companies.

The growth in private sector seed sales has not been accompanied by private plant breeding research. This has been good news for public research canters, some of which have developed closer ties with private companies. However, private interest is concentrated on developing new varieties for profitable markets, which neglects producers of basic crops.

Clearly, the seed industry will play an important role in the diffusion of technology, at least for farmers with the most resources. Some Mexican farmers are already testing varieties of transgenic plants under contract with international firms. For example, a Sinaloa farmer is testing transgenic tomatoes under contract with Calgene. Other producers began field testing of transgenic squash, and an association of potato producers is involved in the development of virus-resistant varieties in collaboration with CINVESTAV-Irapuato and Monsanto. These farmers have a high level of technical competence, substantial infrastructure and resources, and grow high value products for export.

It appears that since the crisis, seeds for crops that are less economically attractive will be left to small specialised firms, but they lack the capital for financing development costs of new varieties. Under present conditions, it is difficult for these firms to create quality material that they can put on the market. Thus there is a pressing need for closer ties between small domestic firms and public research canters, so that these companies can produce improved varieties and satisfy the needs of regions considered to be unattractive segments of the market, which are ignored by the large domestic and multinational seed companies. It is fairly obvious that innovative seed companies can help promote diffusion of biotechnology.

Under the new legislation, government intervention seems to be justified primarily to promote competition, addressing market failures by providing an environment conducive to the development of the seed industry, encouraging competition based on quality of products and services. This implies public incentives for these small enterprises, support for training in seed production technology and infrastructure, providing credit, funding basic research, and even seed production for regions where market failures limit the interest of private companies (López Pereira and García, 1994).

VI. FACTORS DETERMINING SUCCESS OR FAILURE IN THE DIFFUSION OF BIOTECHNOLOGY: SOME LESSONS FROM RECENT EXPERIENCE

Besides a lack of human resources for transferring biotechnology to farmers, we have used empirical evidence from entrepreneurs to analyze the main obstacles to its diffusion.

One of the first biotechnology products on the market was a fermentation process for producing cattle feed called "Biofermel". It was developed in the 1970s by the Biomedical Research Institute of the UNAM. Biofermel has a high protein content, is easily digestible and cheaper than grain-based feed. Despite these advantages, the research group met with indifference for years. The private sector was not the least bit interested in a project with a high degree of uncertainty even though relatively little capital was required.

Then one of the researchers decided to create an enterprise to market the product and he confronted all the obstacles faced by firms dealing in new technology: financial difficulties, bureaucratic constraints and unreliable domestic manufacturers of industrial equipment. After production was finally under-way, marketing became the most serious problem. Cattle raising in Mexico was in a deep crisis which caused a contraction in demand for feed. Furthermore, cattle raisers were highly reluctant to try an unknown product, despite the availability of information about its testing. It was only possible to overcome this attitude by marketing the new feed with the entrepreneur's technical support, primarily by making the most of his technical ability as a specialist in animal nutrition.

Ecología y Sistemas de Rehabilitación Oikos is a small enterprise which produces a vaccine for trees, revitalizing them by using certain ingredients of organic origin. The enterprise mainly operates in the central region of Mexico (around Mexico City) and its main customers are public institutions. The entrepreneur developed the product from knowledge he acquired during a course in Canada. Thanks to the entrepreneur's personal contacts, it was possible to obtain the temporary support of a development bank to carry out field tests. The firm has tried to continue its research with the support of CINVESTAV-Irapuato, but receives no funding.

The main obstacles confronted by this enterprise have been a lack of financing and a cultural resistance to new products. Another important problem is related to the fact that several government agencies have been customers. Thus changes of government are accompanied by administrative changes, making it necessary to begin promoting the product again, which is very costly for such a small firm.

The Laboratorios Agroenzimas, S.A. de C.V. is an enterprise that was created four years ago and works on the production of growth regulators for plant development, foliar fertilisers and additives to improve the efficiency of agrochemicals. It is a small firm aimed at the market of profitable crops like vegetables, flowers and fruit. Its product are of good quality and the firm has begun to export, although it has had to overcome a series of barriers to do so.

The main problem faced by Laboratorios Agroenzimas has been the agricultural crisis. Under these circumstances the farmer sacrifices any input considered unessential and stops buying agrochemicals. This creates considerable market instability and firms which do not have a large financial base cannot compete. Furthermore, demand can also be filled by cheap imports which may be of poor quality The imported products do not always fulfil regulations, which are often poorly enforced. Agroenzimas started a research project partially financed by CONACYT for the production of gibberellic acid, but the project had to be abandoned, because this chemical is produced in China at one-tenth the price and, for this reason, Chinese imports have taken over the Mexican market for gibberellic acid.

The entrepreneur considers the main constraints for developing the business are as follows:

— Regulations for introducing a new product in Mexico are incoherent and constitute an obstacle to product development. A product approved in Mexico cannot necessarily be exported because other countries do not recognise Mexican standards. Thus exporting involved additional investment.

— There is very little information available for industry about foreign markets.

— The cost of the borrowing for any kind of investment is too high.

— Research financing would be important to differentiate products but it is increasingly difficult to obtain funding and this creates a disadvantage by comparison with large multinational companies.

Agroenzimas considers that there are five rules of thumb for surmounting barriers and being successful in this area:

1. Differentiating the product.

2. Providing good service to customers: technical assistance and assuring reliability.

3. Avoiding price wars (very common in Mexico).

4. Undertaking selective distribution.

5. Assuring slow but steady growth with a solid financial base.

The last firm studied was the Corporación de México (CORBIOMEX), a company that has had experience in biotechnology products for agriculture since 1976. In 1989, it made an agreement with Citozyme Laboratories of Utah (USA) to distribute products like biological growth promoters, foliar fertilisers and bioactivated fertilisers for soil. The Mexican firm carries out field tests of the American company's products and distributes them in Mexico. In fact, entrepreneurs consider that, for the moment, research is unprofitable in Mexico and that it is best to import biotechnology products and adapt them to local conditions with the help of research centres.

Bioquímica believes farmers accept biotechnology products because the technology is "clean" they are not a substitute for chemical technology but make its use more efficient. Therefore the market is primarily growing for use with cash crops. The main constraint in Mexico is that credits for agriculture have been reduced and there is no liquidity.

The entrepreneurs interviewed consider the absence of links with academic researchers a serious problem. As we have already noted, this situation is not entirely the fault of the academic researchers. There has been little incentive for private sector technological innovation, and the resulting lack of entrepreneurial understanding of advanced technology has clearly been an obstacle to relationships with academic researchers. This was shown in a project for creating transgenic varieties of tobacco, which was being carried out by CINVESTAV-Irapuato together with the Producers Association.

The work was being done by one of the best plant biotechnology research groups. However, the producers withdrew their financial support because they had lost interest in a project whose results would only bear fruit in the long term. Producers of commercial crops generally prefer to use mature technologies, or even to contract for research with foreign institutions. This reflects a certain distrust of domestic research, but is also due to the researchers' inexperience in working for the private sector. An analysis of eleven biotechnology projects (Solleiro *et al.*, 1992a), revealed that the diffusion of results was questionable from the onset, since the research was on the fringe of market needs. In many cases, relationships were undertaken with firms without adequate contracts or concern for intellectual property rights. Furthermore, development frequently take very long and this implies lost market opportunities.

All these factors inhibit the process of generating, transferring and diffusing technology. In brief, the constraints to the diffusion of biotechnology are, in varying degrees, due to the agricultural situation, and to factors relating to academic research and industry itself. Table 12 also shows that there are problems arising from defining specific policies for biotechnology.

Table 12. **Principal Obstacles to the Diffusion of Biotechnology in Mexican Agriculture**

Relating to the agricultural sector	**Relating to academic research**	**Relating to the industrial sector**	**Relating to biotechnology policy**
Lack of capital	Research without significant links to market	Lack of planning and technology strategy	Lack of financing and tax incentives for industrial R&D
Uneven sectoral composition	Inadequate management of relationships with industrial partner	Small size and limited financial capacity	Preference given to basic research
Conservative attitudes	Lack of human resources	Conservative attitudes towards alliances and joint ventures	No specific promotional instruments
Agricultural education give little emphasis to biotechnology	Evaluation favours traditional academic results	Limited capabilities for R&D, and for monitoring and adopting innovations	Inadequate information systems
Inadequate extension services	High geographic concentration of research facilities		Lack of strategic objectives
Critical economic situation		Low competitiveness in the seed industry	Indifference to biotechnology

VII. CONCLUSIONS AND POLICY RECOMMENDATIONS

Prospects for the Development and Diffusion of Biotechnology in the Agricultural Sector

Mexico has undertaken profound reforms of the legal framework for agricultural and biotechnology development. Important progress has been made in modernizing the seed industry, and in establishing up-to-date approaches to intellectual property rights, biosafety and environmental protection. The opening of the economy and membership in NAFTA constitute powerful catalysts for the modernization of Mexico's agricultural sector. All these developments will promote innovation in biotechnology.

Nevertheless under current conditions, the use of techniques and products derived from the new biotechnology is going to be reserved for the relatively small proportion of farmers with experience using complex technological packages, and working with commercial and profitable crops. The cost of the new biotechnology is still high, especially taking into account that it is usually associated with modern machinery and farming high quality soils. The price of biopesticides on the Mexican market, for example, is still higher than that of chemicals. Furthermore, biopesticides are not as "simple" to use as chemical pesticides, and require more technical support and evaluation. Thus competitive pressures are the main reason for using biotechnology. The vegetable exporters use biopesticides, new varieties and even test transgenic plants to consolidate their position in a market with increasingly rigorous standards.

On the other hand, the biotechnology available in Mexico does not appear to targeted for use by small farmers and peasants. There is still much to do to stimulate their demand and promote access to the latest innovations. In the short term, perhaps the most important thing is developing sound economic and agricultural policies to help overcome the crisis of the agricultural sector, policies involving investments for infrastructure, for promoting market development and technical change. Without major changes, the vast majority of Mexican farmers are unlikely to use biotechnology, especially since domestic biotechnology research lacks strong links with the productive sector and demand is only marginal.

To be sure, Mexico has an institutional base for plant biotechnology, with research facilities, well-trained researchers and some companies that have made initial investments in biotechnology. It is true that this framework is still rather modest, but it can serve as a good springboard for future development. What is lacking is a dynamic interaction among those elements which, at least in part, is a consequence of the absence of a development strategy. Thus there is need for a new approach to promoting the development and use of biotechnology. The last topic of this study will be devoted to suggestions for a policy framework to foster a new biotechnology strategy in Mexico.

Towards a Biotechnology Strategy

In view of the potential of biotechnology in Mexico, developing bioindustry should be a priority; "this implies favouring . . . different capabilities which will permit biotechnology to be created, acquired and used" (Avalos, 1990). This is not only a question of increasing investments in R&D in order to have a greater capacity for scientific research. It is also critical to facilitate the adaptation and assimilation of biotechnology developed in other countries. Thus in addition to improving scientific research and the educational system, it is of fundamental importance to monitor state-of-the art of biotechnology in other countries, its suppliers and trends in its international market.

If innovation is to be encouraged, Mexico will have to discard its traditional approach towards science and technology. A new biotechnology strategy should be integrated into the new approach. This would involve closer relationships between science, technology and the market, for fostering innovations and their dissemination. "In other words, it refers to an institutional framework allowing the linkage of . . . information, equipment, human resources, financial resources, etc., located in different institutions (public laboratories, university research canters, companies, machinery manufacturers, engineering firms, etc.) to facilitate innovation" (Avalos, 1990).

Some recommendations for establishing a biotechnology policy for the agricultural sector in Mexico within such a framework will follow. Obviously, it is not possible to present a detailed plan here, as the starting point would have to be defined together by representatives of the government, private sector and the universities on the basis of existing strengths, weaknesses, and opportunities challenges.

This process for formulating policies should follow a certain logical order so that main actors of biotechnology development become committed to certain common objectives. Thus the first thing is establishing long-term objectives and priorities, a necessity for making strategic decisions. The second step would involve establishing coherent programmes for strengthening the institutional and managerial framework to address the priorities. Sound policy instruments are needed to insure that researchers, enterprises, NGOs and farmers participate in priority projects for introducing biotechnology. Finally, implementation requires continuous monitoring and assessment of achievements and obstacles, to maintain quality of technical aspects, and make timely corrective actions for attaining general objectives. For this purpose, an effective body for gathering statistical information is also needed.

Establishing Long-Term Strategic Objectives and Defining priorities

It is clear that national policies depend on the objectives which, in turn, depend on defining priorities. This would not be a problem if coherent industrial, scientific and technological policies existed in Mexico. As mentioned, however, Mexico does not such national objectives or policies for establishing priorities in biotechnology. We therefore developed a proposal for agrobiotechnology with the participation of researchers, entrepreneurs, civil servants and representatives of the financial system (Solleiro *et al.*, 1993). What we called a "good follower" scenario proposes some general objectives for the development of Mexican biotechnology during the next ten years. As the term "follower" might be perceived negatively, we emphasise that a close follower technology strategy is simply a path for becoming competitive, given the barriers to technology and markets, and the control over fundamental research by the most advanced countries and private companies (Sercovich and Leopold, 1991).

It is true that generic knowledge for the development of biotechnologies is to a large extent still in the public domain and that access to scientific and technical information is relatively simple given modern communication networks. However, the importance of confidential and proprietary information in the development of biotechnology and its applications is increasing. For this reason, the original sources of knowledge, namely public and private R&D labs are assuming control over biotechnology research.

A basic aspect of a good follower innovation strategy, is having highly qualified human resources who can develop research projects and also rapidly choose and assimilate existing technologies. In this scenario, the institutions and companies are highly competent at obtaining generic technologies from which they can develop applications and products for specific demands and markets. Table 13 summarises the main elements of a good follower strategy.

The most important techniques concern post-harvest conditions for vegetables, fruit and ornamental plants, and the protection of crops from insects and other pathogens. Techniques for improving productivity and quality in vegetables and basic grains are also important. This leads also to improvements in vegetables, seeds with a greater oil content, or some other factor which increases the crop's value. Another important priority identified by this group of experts is the application of biotechnology to the treatment of agricultural and agroindustrial waste.

Table 13. **Requirements for a Good Follower Technology Strategy**

- Advanced research and development capabilities.
- Ability to assimilate technologies rapidly.
- Good capability for developing engineering and applications.
- Ability to install medium-size manufacturing plants.
- Good capabilities for making innovations and regular improvements in processes.
- Capability for using generic technology for improving product quality or developing products adapted to specific agro-ecological conditions.
- Capability for developing and/or exploiting commercialization channels
- Timely access to capital and financial instruments.
- Flexible and efficient organizations for transferring and assimilating technology.
- Early entry in the growth stage of a product's life cycle.
- Good scientific, technical and managerial human resources.
- Good capability for establishing co-operation between organizations.
- Levels of excellence in previously selected areas.
- Access to and efficient diffusion of information.

Formulating Programmes

As mentioned, the objective is translating priorities into tangible programmes. This is particularly important, since one of the major obstacles for the design of sound biotechnology policies in Mexico is the practice of establishing programmes unrelated to any defined priorities. According to J.I. Cohen (1994), the elements of primary importance for formulating programmes are:

Research and development

There has to be a balance between basic and applied research in R&D. Basic research should be oriented towards improved mastery of generic knowledge and consolidating the basic knowledge for training new biotechnology researchers. Applied research focused on priority applications should be encouraged. But the basic issue for a R&D program is funding projects sufficiently to improve the probability of obtaining relevant results. Concentrating on a limited number of applications seems to be a better option than sponsoring many projects with insufficient funding. If Mexico's commitment to biotechnology is serious, it will have to increase its expenditure on research.

Human resource development

To implement a biotechnology strategy, the country must have a strong scientific establishment, be able to develop new technology or to adapt technology from other countries. The above mentioned priority-setting exercise (Solleiro and Quintero, 1993), determined that it was essential for Mexico to improve its basic knowledge in disciplines such as molecular biology, cell biology, biochemistry, physiology and microbiology, as well as of crop evaluation, plant breeding, and plant-microorganism relationships. This knowledge can be useful for establishing new training programs oriented towards priority applications of biotechnology.

Collaboration with agricultural research institutions

Greater collaboration between biotechnology canters and the traditional agricultural research institutions is essential for introducing biotechnology to agriculture. Some Mexican institutions have already begun to incorporate biotechnology in agricultural research, by creating micropropagation laboratories or through agreements for joint research. It is imperative to provide incentives for such collaboration.

Information and communication

Even though most important research centres and universities belong to information and database networks, it is still necessary to have facilities for obtaining and disseminating information, as well for communicating between researchers. The basic infrastructure exists for establishing networks and canters of excellence. A centre of excellence is a concept developed in Canada to promote co-operative research in priority areas. It is mainly concerned with facilitating communication and collaboration of high-level researchers in selected fields. Private companies co-sponsor some of these networks as a means of keeping an open window on advanced knowledge. The cost of these networks is not high.

Infrastructure development

Mexican infrastructure for R&D in plant biotechnology is highly concentrated in four or five institutions. Therefore the programme of human resource development should involve the creation of infrastructure in other locations, specially in agriculture research institutions.

Technology transfer and diffusion

In the past, Mexican science and technology policy has essentially involved planning for research. New innovation policies will have to start from demand (OECD, 1994). This implies major changes in the actors involved in biotechnology innovation.

Moreover, under the good follower strategy, new programmes must be created to promote technology transfer from research canters to producers and enterprises, as well as from other external sources. This means that agricultural research canters will have to abandon their traditional linear conception of generating and transferring technology, to become agents for the diffusion of innovations that do not always originate in their research laboratories. This opens up a number of new possibilities. New programmes should be established for assisting producers to select, acquire and adapt foreign technology. Agrobiotechnology institutions can play an important role in monitoring and evaluating the transfer of foreign biotechnology. They can also help insure quality in the seed market by participating in certification and inspection, using advanced biotechnology like molecular markers.

At the same time, programmes jointly sponsored by the government and private sector are needed to improve the level of information about biotechnology disseminated by extension agents.

Policy Instruments

After defining priorities, the next step is implementation with sound policies which encourage participation by the concerned actors. A relatively brief discussion of such policies follows:

Financing

Relevant innovation policy should be based on the notion of catalytic support, which means providing strong initial support for R&D. This is useful for an economy like Mexico's, where R&D is not yet a routine activity in the private sector. Success of the policy would be measured by its success in inducing private companies to do sufficient R&D and innovation of their own, with relatively little government support (OECD, 1994).

This is specially relevant to biotechnology. A special fund would be necessary for financing infrastructure, basic research, collaborative R&D programmes, venture capital, training programmes and technology transfer. Financial incentives have to be attractive for private enterprises, while institutions must reduce bureaucratic procedures and have flexible criteria for approving projects. The biotechnology fund should be permitted to deal directly with enterprises, avoiding intermediation by commercial banks, as past experience has shown that most banks are not up to the challenges of supporting Mexico's modernization.

Training of Human Resources

Biotechnology involves the development and application of molecular biology, biochemistry, microbiology, cellular biology, as well as of advanced engineering and agronomic techniques. Thus new teaching programmes which include the latest developments in these field are urgently needed. The academic infrastructure needs to be considerably improved. It is also important to provide incentives for interdisciplinary and interinstitutional efforts such as the National Graduate Education Programme on Biotechnology, created recently by a few public universities. The agricultural universities are not involved in this initiative. The involvement of the agricultural education system in biotechnology should be encouraged by granting it special funds and fellowships.

Another good example of training for producers is the FIRA Centre, already mentioned. This type of institution could be an excellent way for imparting the technical knowledge needed by the end users of agricultural biotechnology..

Another problem is that most Mexican researchers and managers have limited understanding of the requirements for successful development of biotechnology-based enterprises and products. Access to new technologies is limited because of a lack of sufficient timely information about markets and technical opportunities. Many enterprises know little about transferring technology. Thus solid managerial skills must be developed. Training courses and seminars could help entrepreneurs and researchers deal with the business aspects of biotechnology innovations.

Information

Improved access to technical and market information is essential for helping enterprises acquire new biotechnology, and for strengthening their bargaining power in technology transfer negotiations. Therefore, a network of information canters must be created, incorporating the latest advances in retrieval and dissemination, as well as having qualified personnel able to provide the latest information to enterprises and research institutions.

International Co-operation

Mexico's international scientific co-operation involves many institutions Biotechnology should be a priority in international co-operation. Nevertheless, international collaboration still largely depends on individual contacts, many of which were established while Mexican students were engaged in doctoral studies abroad. Institutions of the national agricultural research system have been rather passive with respect to international scientific co-operation, mainly because of the shortage of human resources in this area.

Close international ties have demonstrated their value for higher education and training programmes in basic science, but play a lesser role in technologically or commercially oriented projects. Therefore, making the best possible use of international co-operation should be an immediate priority in agricultural biotechnology, where there are a relatively large number of opportunities (IBS, 1994). Institutions require better organizational procedures for managing international relationships and collaborative programmes to benefit from these opportunities.

Support for Enterprise Creation

It has been demonstrated that new technology-based enterprises are an efficient mechanism for biotechnology diffusion. The new seed legislation in Mexico, for instance, has led to the creation of private companies producing varieties and hybrids, and serving regions long ignored by large national and multinational seed companies, which do not consider these segments of the market attractive. However, in order to realise their potential, these companies should be given much stronger support to cope with the difficult initial stages of a start-up and for consolidating their position in the market.

Tax Incentives

Biotechnology development requires a tax system that encourages private sector R&D. There are practically no tax incentives for innovation under existing policies. Priority should be given to formulating the appropriate tax incentives for R&D and training of human resources by the private sector.

Technical assistance and extension systems

Modernization of Mexico's agricultural will require significant improvements in the extension system. A network of technical canters should be created, with the support of government agencies, farmers' associations, the food industry, financial institutions (like the FIRA) and research institutions, in order to provide farmers with information and technical services. Financial support to these canters could be temporary so that technical services would tend to become self-supporting in the future.

Promoting Links between Research Institutions and the Productive Sector

In a general way, co-operation among enterprises, universities, and public and private R&D establishments promotes innovation. Such interaction is especially important In biotechnology as in all advanced technologies. The establishment of technology transfer or liaison offices will facilitate co-operation and the diffusion of research findings. Special incentives may be necessary to help small firms collaborate with research institutions.

Regulatory Issues and Intellectual Property Rights

Mexico has made significant advances in the legal framework for biotechnology but relatively little has been done to insure enforcement of the new legislation. Moreover, capabilities for evaluating the benefits and risks of new biotechnology are inadequate. Significant efforts will be required to translates laws into effective instruments for innovation. When appropriate, the patentability of intellectual property rights should be respects. At the same time, the patent office should be to make information on new patents readily available.

Finally, we emphasise that the development of plant biotechnology products and techniques can be a long process. Public institutions and industry must take a longer-term view if they expect to participate in the biotechnology revolution. Moreover, a similar outlook must be encouraged among agricultural producers who will reap the immediate advantages from the new technology.

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