The Emergence of Biotechnology-Related Industries in Mexico

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Abstract

This paper analyzes the emergence of biotechnology-related industries in Mexico. It is assumed that there are three important features for studying this process: (1) biotechnology cannot be understood as a single sector or industry; (2) new biotechnology firms have emerged from the very beginning of the biotechnology revolution, suggesting thus that the creation of high-level scientific capabilities is crucial to develop biotechnology-related firms; and (3) substantial part of the biotechnology research is actually carried out by public laboratories and universities. The paper concludes discussing on the importance of public funding for developing a competitive biotechnology-related firms sector.

Keywords: biotechnology innovation, government policy and Mexico.

Resumen

Este trabajo analiza el surgimiento de las industrias relacionadas a la biotecnología en México. Se asume que hay tres rasgos importantes para estudiar estos procesos: (1) la biotecnología no puede ser entendida como un solo sector o industria; (2) las nuevas empresas biotecnológicas han surgido de la revolución biotecnológica; (3)

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una parte importante de la investigación biotecnológica se lleva a cabo en laboratorios públicos y universidades. El trabajo concluye discutiendo la importancia del financiamiento público para desarrollar un sector competitivo de empresas ligadas a la biotecnología.

Palabras clave: biotecnología, innovación y México.

Clasificación JEL: Z00, O31, O38, O54.

Biotechnology and industry

This paper analyzes the emergence of biotechnology-related industries in Mexico. The main ideas featuring the analysis are (McMillan *et al*. 2000): (1) biotechnology cannot be assumed as a single sector or industry, but a set of science-based processes of products and tools; (2) new biotechnology firms emerged from the very beginning of the biotechnology revolution, demonstrating that the creation of high-level scientific capabilities in biotechnology-related firms is crucial to develop them; and (3) it is observed that a substantial part of the biotechnology research is actually carried out by public laboratories and universities.

The paper also makes a revision of the conditions under which biotechnology-related industries emerged in Mexico. The case of the Mexican biotechnology-related developments exemplifies the challenges of managing technological innovations in an emerging economy. The remaining of this paper is organized into three sections. Section 1 gives a global view of biotechnology activities, emphasizing the most important developments observed in the last years. Section 2 discuses the conditions under which biotechnology-related industries emerged in Mexico, synthesizing some studies developed in relation to the Mexican case. Finally, Section 3 presents some concluding remarks.

The emergence of biotechnology and underlying industries

Biotechnology is a set of technologies and there are several opinions about the

precise date biotechnology activities formally began. The term biotechnology was firstly introduced in 1919 by the Hungarian agricultural engineer Karl Ereky (Ruttan, 2001). However, modern biotechnology activities are related to the discovery of the structure of the deoxyribonucleic acid (DNA), the hybridoma technology developed by James Watson and Francis Crick, and other important advances in molecular biology (Solleiro 1995; Gonsen 1998; Wagner 1998)[1].

The term biotechnology was adopted to designate a variety of biological transformations. Strictly speaking, biotechnology is not an industry or a sector. Modern biotechnology has become a broader name and its practices are a generic set of biochemical and bioengineering techniques that use living organisms to make or modify products, to improve plants and animals, or to develop and use microorganisms in pharmaceuticals, food processing and some other industries. Biotechnology thus refers to the field of industrial activities based on biological processes involving new techniques (Gonsen, 1998; Solleiro, 1995). Biological processes are those that involve living organisms (microorganisms and living cells of plants or animals) which are based on the application of scientific and biological methods processes, as well as genetic engineering principles covering a wide range of disciplines (Gonsen, 1998; McMillan, 2000).

There are three main areas where biotechnology techniques have largely been applied: (1) pharmaceutical; (2) agricultural; and (3) chemical utilizations. The pharmaceutical industry has become the most important from a commercial perspective. The development of this industry in relation to contributions and applications in biotechnology have implied the application at the same time of many knowledge disciplines, such as biochemistry, cell biology, molecular genetics, protein chemistry, enzymology and computer science (Ruttan, 2001). Therefore, this new way of thinking in pharmacology has contributed to reshape the structure of this industry, making more profitable the development of new products and processes (Piachaud and Lynas, 2001). Table 1 synthesizes the most important business event developments in modern biotechnology.

[1] In fact, DNA was discovered before 1938 by Max Delbruck, but nowadays it is well recognized that the former events already pointed out here were the starting point to modern biotechnology-related industries.

Table 1

Modern biotechnology industrial developments (1953-1990)

Year	Science event	Business event
1953	Watson and Crick-Double Helix	
1970	1st synthesis of a gene (non-functional)	
1971	Restriction enzymes discovered	Cetus founded
1972	Initial work with embryo transfer	
1973	Cohen and Boyer perfect genetic engineering techniques	
1975	1st monoclonal antibodies (MAbs) produced	Agrigenetics founded
1976	DNA Sequencing discovered 1st working synthetic gene	Genentech founded
1977	1st expression of human gene in bacteria	Genex founded
1978	High level structure of virus 1st identified; recombinant human insulin 1st produced	Biogen and Hybritech founded
1979	Human growth hormone 1st synthesized	Centocor founded
1980	Supreme Court: life forms are patentable	Amgen, Calgene and Genetic Systems founded
1981	Gene-synthesizing machines developed	1st MAb diagnostic kit approved; Applied Biosystems, Chiron, Genetics Institute and Xoma founded
1982	Rat gene transferred into mice 1st synthesized vaccine	FDA approves 1st r-DNA product for use (human insulin)
1983	1st artificial chromosome; 1st field test with altered bacteria is delayed; 1st markings for inherited diseases found in genes	1st sales of r-DNA product
1984	1st genetic engineered vaccine	
1985	Genetic marketing found for kidney disease and cystic fibrosis	FDA approves human growth hormone (2nd genetic engineered drug)
1986	1st field trails of genetic engineered plant	FDA approves 1st genetic engineered vaccine
1987	1st field trial of a recombinant bacterium	Tissue plasminogen activator (TPA) approved
1988	1st US patent for a vertebrate (transgenic mouse)	FDA enacts accelerated regulatory process
1989	1st field trial of a recombinant viral crop protectant; cystic fibrosis gene discovered	FDA approves EPO; IL-2 approved in parts of Europe
1990	1st human gene therapy; 1st tests/ applications of microbials to combat oil spills	Roche acquires Genentech 1st genetic engineered food product

Source: Gonsen (1998).

An important feature characterizing any biotechnology firm is its closeness to scientific and technology developments in public laboratories and universities. Nelson (1998) stresses the importance of this feature in relation to a theory of economic growth and technological change. In the case of the biotechnology-related industries, universities and research laboratories are effective knowledge suppliers to firms, making this network more likely to exploit commercially new knowledge (Zucker and Darby, 1996). In this sense, it is recognized an important change in the technological paradigm and trajectory in the case of the industries supported by biotechnology knowledge (Audretsch and Stephan 1996; Patel and Pavitt 1991; Piachaud and Lynas 2001). This principle implies that government financial support to R&D should improve the capacity to innovate. Lastly, this scheme facilitates the possibility of cooperation between non-profit R&D institutions and firms in order to develop a technology infrastructure. The idea is to construct a network of public and private institutions, and firms in order to share knowledge to improve the innovative capacity. Indeed, cooperation between public sector institutions and industry makes public sector institutions aware of the demands of the market in order to conduct innovation efforts (Peters *et al.* 1998).

In relation to the emerging countries, biotechnology developments have been more successful in areas related to agricultural activities. In these countries, R&D biotechnology activities are important issues for agriculture, food processing, environmental management and pharmaceuticals research programs (Wagner, 1998). These efforts have largely contributed to develop new markets, such as transgenic crops, virus-resistant tobacco, bovine somatotropin (rbST) for enhancing milk production, herbicide resistance, insect resistance and disease resistance in crops are other examples of biotechnology products found in these countries (Ruttan, 2001; Solleiro, 1995). Table 2 shows some important biotechnology applications for agricultural products by commercializing companies.

In many ways, biotechnology has been commercialized in almost all countries. However, the efforts and resources needed to develop successfully a new product are highly important. A key feature of biotechnology is that its commercial developments depend highly on external knowledge in order to enhance firms' internal innovation efforts (McMillan, *et al.*, 2000). In this sense, it would be

Table 2

Biotechnology applications in the agriculture sector

Product/attribute	Firms	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/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.

interesting to identify the most important factors when developing successful innovations. There are many variables affecting firm's performance and innovation in biotechnology-related industries (Fontes 2001; Janszen and Degenaars 1998; Niosi 2000a, 2000b, 2003): (1) the level and nature of a scientific knowledge base; (2) the role assumed by the government; (3) technology suppliers; (4) a favorable home market; (5) a fast consumer acceptance of innovative products; (6) consumer

aversion of the innovation; (7) the nature of an adequate patent law regime; (8) number of years a firm is in the market; (9) firms focused to produce a specific product; (10) firms actively patenting; (11) the existence of venture capital markets; (12) exporting activities; and (13) establishment of strategic alliances of those firms with foreign corporations.

However, high dependency on external knowledge is a deeply important characteristic featuring biotechnological firms. Indeed, public institutions play an important role developing a knowledge-base in biotechnology activities. The absorptive capabilities model proposed by Cohen and Levinthal (1989 and 1990) is a useful framework to explain how some firms are more capable to acquire external knowledge. The absorptive capacity allows firm to recognize, assimilate and apply new information to commercial ends (McMillan, *et al.* 2000). However, Cohen and Levinthal's model implies that firm's capacity to innovate depend both on internal and external elements, and thus the exploitation of basic scientific discoveries requires a firm to learn continuously beyond its boundaries. The industrial application of biotechnology knowledge requires a country to possess many other specific competencies. Biotechnology firms actually play a key role in transferring knowledge from universities and public laboratories to the marketplace. Solleiro (1995), for example, identifies the presence of a manufacturing base, industrial know-how, marketing and distribution capabilities, and experience with regulatory regimes as the most important variables imposing restrictions to firm's innovation efforts. Thus, from the absorptive capacity framework, this analysis suggests that the possibilities of a firm in a country to exploit new market and opportunities will depend on its possibilities to acquire new knowledge.

McMillan *et al.* (2000) concludes that trends in the biotechnology-related industries have made a great number of manufacturing firms to focus their R&D efforts in their own home countries. Indeed, these authors have also pointed out that biotechnology markets and industrial developments have lead to a non-technology globalization case. The empirical fact that firms' efforts to develop a biotechnology knowledge-based centered on specialized universities confirm these principles pointed out in this section. Table 3 shows the results achieved by some studies on biotechnology:

Table 3

Management and economic research on biotechnology activities

Author(s)	Results
	General research
Audretsch and Stephan (1996)	Geographic proximity is important in the university-biotechnology relationship, even with e-mail, faxes and other electronic communications, and that the specific role played by the university scientist dictated the geographic necessities
Deeds et al. (1997)	The publication record of a biotechnology scientific team and the firm's physical location are positively correlated with the amount of capital the firm can raise in its initial public offering
Lane et al. (1991)	Study developed from the perspective of the SD approach. Analysis on firm's growth strategy and the process to capture management team knowledge and to represent unique structural features of biotechnology manufacturing and marketing
Liebeskind et al. (1996)	Firms who engage in joint research and publish with academic institutions are more effective at sourcing new scientific knowledge than those who do not have joint activities
	Improved capacity for innovation as a result of government support to R&D institutions.
Lois et al. (1998)	The importance of cooperation between non-profit R&D institutions and firms to develop a technology infrastructure or a national system of innovation
McMillan et al. (2000)	Analysis of the importance of public science in biotechnology innovation developments
Powell (1998)	Analysis of the importance of interorganizational linkages to knowledge diffusion, learning and technology development. Two sources of collaboration: contractual relationships (R&D partnerships or joint ventures) and informal relationships (participation in technical communities)
Singh (2001)	Analysis of the importance to develop commercialization skills in the firm as biotechnology innovations moves away from the phase of R&D to commercialization of new products into the marketplace
Zucker and Darby (1996)	The critical role of 'star' scientists in when and where biotechnology firms appeared, and how successful those firms become
Zucker and Darby (1997a and 1997b)	How an incumbent pharmaceutical firm adopt a biotechnology approach (drug design vs. random testing) in its research and development efforts
	Analysis of biotechnology activities in specific countries
Casper (2000)	Managerial practices and the economics of biotechnology in Germany
Escobedo and Sporleder (2002)	Management technology and biotechnology in Mexico
Fontes (2001)	Biotechnology development analysis in the case of intermediate economies like Portugal
Gonsen (1998)	Firm development capabilities and biotechnology development innovations in reference to the case of Mexico
Niosi (2000b and 2000a)	Insights on biotechnology developments in Canada within an evolutionary and managerial framework
Niosi (2003)	Development analysis of dedicated biotechnology firms (DBFs) in Canada
Patel and Pavitt (1991)	Much of the intellectual scientific base for biotechnology is located in California and the Boston area
Qaim and Falconi (2001)	Agricultural biotechnology developments in Mexico in relation to the institutional and policy framework of this country. It also analyzes some commercial and market restrictions imposed by the lack of an adequate biotechnology policy
Solleiro (1995)	Analysis of pubic policy and biotechnology tendencies in Mexico
Thomassin and Cloutier (2001)	Analysis of reinforcing and balancing regulatory pressures on the performance of agricultural and food biotechnology industries in Canada
Walsh, V. et al. (1995)	Analysis on firm formation in three different countries: France, Britain and Canada
Wagner (1998)	Strengths and weaknesses of Mexican biotechnology R&D activities and industrial developments

Source: Own elaboration.

Biotechnology creates new challenges for business management in that achieving competitiveness by biotechnology-related may require improving their skill requirements. In this sense, Singh (2001) mentions that there are at least four critical skills needed by a firm for having success in biotechnology business: (1) scientific and technical knowledge (project design, good laboratory practices, information searching ability, and computer knowledge); (2) technology development (patenting and protection of intellectual property, understanding the full development process, and understanding the direct commercial application of the research); (3) product and process development (knowledge of pre-clinical drug development requirements and their specifics, formulation development, knowledge of steps required to gain approval and to sell in international markets, product strategy for moving the technology to market, and ability to create alliances/ partnerships/licenses/contracts and process development); and (4) business administration (marketing and promotion, sales/distribution, organizational development/human resource management, general management, entrepreneurial development/human resource management, general management, entrepreneurial know-how, and the ability to sell the technology).

Biotechnology industry in Mexico

There are only a few studies on biotechnology-related industries in Mexico. From a management and economics perspective, the most important analysis of Mexican biotechnology-related industries are: Escobedo and Sporleder (2002), Gonsen (1998), Qaim and Falconi (2001), Solleiro (1995), and Wagner (1998). The development of biotechnology-related industries in Mexico exemplifies the challenges of managing technological innovations in an emerging economy. Actually, the potential impact of biotechnology scientific R&D activities on the Mexican economy would be highly important (Wagner, 1998).

Solleiro (1995) reports that the potential of biotechnology R&D developments for industrial and commercial purposes will be very important for food and agricultural sectors in the next years in Mexico. Therefore, it is a priority to identify the major institutional and policy incentives to support the development

and diffusion of biotechnology innovations. However, from the experience in some other countries, this author suggests, the constraints that prevent or limit the use of the new biotechnology products and methods must lie at the core of the analysis. From a global perspective, there are two main development patterns in the agricultural biotechnology that must faced emerging economies (Qaim and Falconi, 2001; Solleiro, 1995; Wagner, 1998). First, given that biotechnology developments are almost concentrated in highly industrialized countries, emerging economies will require high-levels of scientific research and capital investment in order to access that knowledge. Besides, it is also imperative to develop capital risk markets. Second, biotechnology innovations are mostly controlled by large multinational companies, and thus this is the case of biotechnology agriculture innovations (Table 2). Therefore, Mexican biotechnology-related firms' objective should be to create adequate conditions to develop biotechnology innovations and to take them successfully into the marketplace. In so doing, these firms must develop adequate management competencies to compete in markets. In the case of Mexico's biotechnology activities, Solleiro (1995) has pointed out that without modifying the structural constraints drew from the recently past industrializing process, biotechnology-related industries will continue to be pushed by scientists without strong links to production and remaining demand-pull as a weak market force. Moreover, Fontes (2001) suggests that in the case of emerging economies, many of these countries dispose of a substantial scientific knowledge-base and an industrial structure with a great number of weaknesses (e.g., technological levels of their firms, high dependence on imported technology, limited degree of industrial integration, etc). Indeed, national systems of innovation in these countries show insufficiencies in relation to communication and complementarity between public and private institutions and universities.

Unfortunately, biotechnology R&D activities in Mexico have not supported systematically the economic development process carried out in this country (Gonsen, 1998; Wagner, 1998). Although there have been important efforts to acquire an adequate scientific knowledge-base, the attempts have not been sufficient to cut down the distance between the generation of new knowledge and new innovations. Wagner (1998) suggests that the lack of entrepreneurship is one

of the most important obstacles in the development of commercial biotechnology innovations in Mexico. Indeed, there is a lack of interest by Mexican scientist to develop innovations, and this is actually the problem in agricultural biotechnology-related industries in this country. As Wagner (1998) has pointed out, technological innovations require not just a scientific base, but also subsequent transfers to the marketplace. From this perspective, Mexican biotechnology firms need to be more engaged in international market requirements in terms of new products and processes. However, Wagner (1998) and Qaim and Falconi (2001), for instance, stress the importance to find adequate mechanisms in order that economic and political factors facilitate science developments, and then industry lead to the development of markets for commercial biotechnology innovations.

In a few words, Fontes (2001) mentions that biotechnology industrial developments are determined basically by two factors: (1) the characteristics of the technology in relation to the scientific knowledge in a country; and (2) the country-specific factors (level and nature of the scientific knowledge base, the institutional set-up, and the role assumed by the government). These elements determine together country's ability to exploit new opportunities and appropriate the respective results. In particular, the future of agricultural biotechnology-related industries in the emerging economies depends on how well these countries will be able to select, acquire, adapt, develop and diffuse new products and processes. Moreover, these capabilities are function of their scientific and technological capabilities, entrepreneurial skills, as well as public policies to promote the development and diffusion of new innovations (Solleiro, 1995). In this sense, it is important to be aware of the following features when a biotechnology innovation developed (Fontes 2001): (1) a high-level creation of scientific capabilities is crucial given that biotechnology is a science-based industry; (2) there must be an efficient transfer system between the producers and users of the technological knowledge, given that a substantial part of these capabilities are located in public research organizations; (3) the industrial application of biotechnology requires: i) competence in older biology-related technology processes, ii) the presence of a manufacturing base, and iii) knowledge of industrial know-how; and (4) it is also important to have some complementary assets which commonly lie in the private sector, such as marketing and distribution.

In relation to Mexico, a complete explanation of the dynamics of biotechnology-related firms and their linkages established with other industries should come from both, the scientific and industrial perspectives. In this sense, it would be interesting to make some comments in relation to the legal framework of the institutions and networks within biotechnological activities are carried out in Mexico.

The *Consejo Nacional de Ciencia y la Tecnología* (CONACYT), for instance, has estimated that only 1 to 5 percent of the 22,600 scientists in Mexico work in industry. Specifically, the biotechnology sector in this country lacks developed management capabilities, entrepreneurial attitudes among scientists, and market mechanisms to support innovation developments. Solleiro (1995) concludes that in the case of the Mexican biotechnology sector this pattern is due to a lack of public policies to support the development of this sector. Table 4 summarizes technology policies implemented by the Mexican government over the last three decades.

It is important to mention that the *Progama Nacional para el Desarrollo Tecnológico y Científica 1984* (PRONDETYC) was the first effort to establish what we would know as national biotechnology system of innovation. Effectively, this program followed to support R&D activities related to new industrial applications, as well as to establish networks between different institutions working in specific technical areas. The objective followed by this program was to coordinate specific efforts to work on the development of new biotechnology products (Solleiro, 1995). In fact, this program is at the origin of the development of important research centers on biotechnology that are now the basis of the biotechnology research capabilities in Mexico. In the same way, the *Programa Nacional para la Modernización de la Ciencia y la Tecnología 1994* had an outstanding importance and it established that government would support only scientific developments, giving the responsibility for technical modernization to the private sector. Actually, this program led to important advances in relation to the latter, as it recognized the principle that innovation is important for competitiveness. The fact is that it had no specific programs to support biotechnology innovation (Solleiro, 1995).

Solleiro (1995), Gonsen (1998) and Wagner (1998) mention in their

Table 4

Biotechnology promoting policy in Mexico

Year	Policy / main features
1976	*First official science and technology policy* (in force just for two years): • It contained agricultural and agroindustry objectives • Biotechnology was not explicitly mentioned
1978	*Programa Nacional Indicativo para la Ciencia y la Tecnología* (in force until 1982): • It contained agricultural and agroindustry objectives • Biotechnology was not explicitly mentioned
1984	*Programa Nacional para el Desarrollo de la Tecnología y la Ciencia* (PRONDETYC) (in force until 1988): • It contained explicit guidelines for biotechnological development • It gave priority to agroindustry, and nutrition and health: o Use of agricultural produce and forestry waste products for animal food o Studies on the biodegradation of lignocellulose waste o Development of biotechnology like genetic engineering, tissue culture and ezyme engineering o Bioengineering support o Unicellular protein production o Better use of sugar cane and its by-products
1994	*Programa Nacional para la Modernización de la Ciencia y la Tecnología:* • Promotion of scientific achievements to meet international standards • It contained not explicit guidelines for biotechnological development: o No specific policy or program dedicated to the promotion of biotechnology o Spontaneously, biotechnology has received special treatment from CONACYT due to growing scientific demand in this area • No specific programs to support biotechnology innovations
2001	*Programa Especial de Ciencia y Tecnología 2001-2006*: • It gives to biotechnology activities and research a central role to consolidate the national system of innovation in Mexico: o Program focused to the promotion of biotechnology research activities in petroleum, agriculture, and environmental application sectors o It establishes the interest of Mexico to promote cooperation with other countries like Canada, the European Union, Cuba, Argentina, and India

Source: PECYT 2001-2006; Solleiro (1995).

analysis the importance of various scientific disciplines such as molecular biology and genetics in relation to biotechnology research. In the case of Mexico, these disciplines are developed just in some universities and research centers, and thus bioengineering related to production scale-up are concentrated in those universities,

governmental research centers and international organizations. Indeed, research activities in these centers and universities involves the generation of new knowledge, techniques and processes. But in the case of this country, biotechnology firms focus chiefly on quality control and adaptation of existing products to local market conditions and there is no strong links between firms and universities (Gonsen, 1998; Wagner, 1998). However, there are several examples of successful Mexican firms who have taken new products into the market. These firms operate on a relatively small scale but they have the capacity to increase their level of production as demand would increase. Table 5 shows a sample of these firms now operating in the Mexican market.

Table 5

Biotechnology mexican firms

Firm (Private/ Public)	Location	Species	In-house research	Links with public research centers	Future plans
Biogenica Mexicana, S.A. de C.V. (Private)	Mexico City (office) Michoacan (labs)	Gerbera Gyposophyla Dieffenbachia Caladium agave Spatiphyllum Singonium anturio Woody	Technology adaptation	CICYUNAM	
El Rancho La Joya (Private)	Atlixco, Pue.	Orchidis	No	No	Micropropagate other species such as roses for export
Gota De Vita (Private)	Huitzilac, Mor.	Potato	No	No	
Invernamex (Private)	Tepoztotlan, Mex.	Gebera gyposhyla Strawberry Raspberry potato Banana pineapple	Technology adaptation	UACH	Go into export market
Rancho Providencia	Toluca, Mex.	Potato	No	UACH	
Viveros El Morro	Mexico City	Spatyphyllum Singonium			
Vivi Toluca (Private)	Toluca Vally	Potato		INIFAP	
Fira (Bank of Mexico) (Public)	Tezoyluca, Mor.	African violet Gerbera Chrisanthemum Strawberry	Yes	UACH	Transfer micropropagation methodologies to small producers

Source: Solleiro (1995).

In terms of the institutions carrying out biotechnology research in Mexico, Wagner (1998) found some interesting facts. The *Instituto de Biotecnología* (IBT) (*Universidad Nacional Autónoma de México*, UNAM), for instance, concentrates about half of the total investment made in biotechnology research in Mexico since 1990. Actually, this university is the most important in terms of the quantity of research projects developed by all universities and research centers in Mexico. Besides, this author suggests, the majority of scientists working in the IBT are among the finest Mexican doctoral-level scientists in disciplines directly or indirectly associated with biotechnology and bioengineering. However, there are some other successful biotechnology-related academic institutions in Mexico, supporting biotechnological research activities. For example, *Centro para la Investigación y Estudios Avanzados* (CINVESTAV), *Universidad Autónoma Metropolitana* (UAM) and *Centro Internacional para el Mejoramiento del Maíz y del Trigo* (CIMMYT) are among the most important. Actually, *Centro Internacional para el Mejoramiento del Maíz y del Trigo* (CIMMYT) is a prominent internationally supported agricultural research center in biotechnology well known in Mexico and abroad.

Summarizing, the most important feature of Mexican biotechnology activities are: (1) projects undertaken in various Mexican laboratories are mostly associated with industries such as food processing, plant and animal agriculture; (2) there are also some projects in environmental management and pharmaceuticals; (3) Mexican biotechnology researchers tend to pursue basic projects of general nature and do not focusing on specific needs of the Mexican market; (4) the majority of the Mexican scientists aim to publish in prestigious academic journals favoring basic research of interest from abroad (Gonsen, 1998; Wagner, 1998); (5) in consequence, not too many scientists are attached to the biotechnology private industry; (6) Mexican researchers do not patent; (7) investing in long-term R&D projects is not a priority within most Mexican firms; (8) Mexican firms tend to acquire a substantial amount of technology-based products or processes from industrialized countries; (9) firms perceive little competitive advantage in hiring scientists, particularly when the technology can be obtained cheaply from abroad; and (9) most of the biotechnology-based products that have been commercially introduced in Mexico are imported. In short, the latter statements suggest that

local firms have not been able to develop a biotechnology market in Mexico. The reasons are that Mexican firms are not significantly important in relation to biotechnology transnational firms. There are insufficient entrepreneurial attitudes among Mexican scientists. Mexican scientists are turned away from collaborating with commercial partners.

Finally, Rosenberg (1976) has pointed out the importance of commercial talent to develop and to capitalize on knowledge. Technological innovation requires not just a scientific knowledge base, but also its subsequent transfer to the marketplace. In effect, this author has pointed out the fact that an active and creative scientific establishment in a country would make important contributions to economic growth of a country will depend upon a whole network of institutions and motivations outside of the scientific community. Moreover, translating new scientific knowledge into more productive techniques and product innovations requires inventive abilities and commercial talent. In the case of Mexico, there is a kind of limitations, such as inadequate national science policy, regulatory confusion and no tradition of entrepreneurship in the infrastructure surrounding the scientific and industrial communities that is responsible for the absence of a culture linking science, technology and industry (Wagner, 1998). Finally, it is important to mention that in 2001 the Mexican government issued the *Programa Especial de Ciencia y Tecnología 2001-2006* (Pecyt). The main objective of this program is to integrate and coordinate needed efforts to continue developing the scientific and technological activities in Mexico. This program emphasizes the importance to integrate scientific and technological activities into the production sector, and recognizes the importance of the innovation processes to compete in the global economy. In the same way, this program defines important objectives to achieve in the long-term. In a few words, the *Programa Especial de Ciencia y Tecnología 2001-2006* (Pecyt) establishes three main objectives: (1) to have a State policy of science and technology in Mexico; (2) to improve the scientific and technological capacity in this country; and (3) to increment Mexican firms competitiveness supporting their innovation capabilities. In the same manner, the program defines five strategic areas of knowledge to develop: (1) information technology and communications; (2) biotechnology; (3) materials; (4) design and manufacturing processes; and (5) urban

and rural infrastructure developments. The *Programa Especial de Ciencia y Tecnología 2001-2006* (Pecyt) is ambitious, as it searches to make Mexican science and technology highly competitive.

Conclusions

This paper analyzed the emergence and development of biotechnology activities with special reference to the case of Mexico. The paper stressed the idea that government financial support for funding R&D at public research institutions and universities should result in an improved capacity to innovate. In this sense, the future of biotechnology applications and firm developments would depend on firms selecting, adapting, developing, and diffusing new products and processes. This idea was confirmed by the analyses developed in the case of other countries. In the case of Mexico, the most important advances and applications developed in this case have been made in relation to agriculture. However, the developments of biotechnology-related industries in Mexico in the next future should correspond to the needs expressed in other industries and sectors. In this process, public financial support for developing biotechnology research and innovations to the marketplace should be a cornerstone.

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