Innovation in the Agri-Food Sector in Latin America and the Caribbean

José Luis Solleiro and **Rosario Castañón,** National University of Mexico

Karla Rodríguez, CamBioTec, A.C.

Olivia Mejía, National University of Mexico

Agri-food systems are fundamental to development. Over and above their contribution to a country's gross domestic product (GDP), which is less than the contribution of the manufacturing and services sectors, the multiple strategic functions of agriculture in economic, social, and environmental development determine that its participation is far greater than its share of GDP.

The agri-food sector faces the global challenge of providing enough food, feed, fuel, and fibre to meet growing and changing demand. The agricultural innovation system needs to develop and distribute innovations able to enhance productivity and sustainability along the supply chain, while helping the sector cope with climate change issues.[1] In developing countries, when talking about rural development it is fundamental to consider the additional challenge of strengthening rural societies and addressing the sustainability challenge, paying particular attention to social inclusion and equity.

The food processing industry is typically described as a relatively mature and slow-growing area of business that displays a relatively low level of research and development (R&D) investment and is quite conservative in the type of innovations it introduces to the market. The main reason for this characterization relates to end-customers, who are usually wary of radically new products and changes in consumption patterns. Nevertheless, the recent stringency of legal requirements related to safety and health transforms food product and process innovation into a highly complex, time-consuming, and risky endeavour. Moreover, recent changes in the nature of both food demand and food supply, coupled with an ever-increasing level of competitiveness, have rendered innovation not only an unavoidable corporate activity, but also one that is increasingly vital for overall agribusiness profitability.[2]

This chapter analyses the main sources of innovation for agri-food systems and current trends in technological change, with an emphasis on biotechnology. It also includes a review of the scientific and technological activities necessary for innovation in the agri-food sector. Finally, the chapter adopts a system's approach and includes an analysis of the role of the different actors of innovation in the sector.

Innovation in the agri-food sector

An innovation system for food and agriculture includes both participants of the supply chain (suppliers, producers, agro-industrial processors, distributors, exporters) and government workers and those involved with universities, research institutes, outreach and development agencies, and so on. Policies, legal frameworks, and attitudes that encourage and guide knowledge incorporation processes, technology, and value-added production also complement the concept.[3]

In the case of agriculture, innovations commonly originate with suppliers; these can be considered 'process innovations' because they relate to production techniques—for example, the adoption of improved seeds; equipment for irrigation, harvesting, and packaging; and information management technologies—as well as improvements for quality assurance and farm management. According to the Organisation for Economic Co-operation and Development (OECD),[4] suppliers of farmers develop product innovations such as improved seeds and animal breeds, agricultural machines, irrigation systems, and greenhouses. The same happens in food processing industries, which produce product innovations such as particular foods to satisfy special niche markets (organic foods, for instance), functional food ingredients, and nutraceuticals (any products with extra health benefits derived from food sources) as well as enhanced raw materials from agriculture for industries such as the chemical, pulp, and paper, and pharmaceutical industries.

The value chain: Complex and evolving

Innovations are now common along the value chain, which is extremely complex and multi-layered with a wide range of actors who participate

Table 1: Summary of innovations for the agri-food sector, 2012–17

Technology	Main innovations	Purpose or expected results
Agrochemicals		
Fertilizers	• Nano-fertilizers that supply one or more nutrients to plants and enhance their growth and yields • Nano-materials that improve the performance of conventional fertilizers	Nano-fertilizers can significantly improve crop growth and yields; enhance the efficiency of fertilizer use; reduce nutrient losses; and/or minimize adverse impacts on the environment.
Herbicides	• Herbicide tolerance traits (either from mutant selection or genetic modification) and safeners*	Improved safeners prevent herbicidal injury to crop plants without reducing weed control.
Pesticides	• Safety in manufacture and use • Convenience for the user • Ease of pack disposal or re-use • Reduction of the amount of pesticide applied • Reduction of waste and effluent of all kinds • Nano-encapsulation	Developments in pesticide formulation technology and novel formulation types, sometimes in special packaging such as water-soluble packs, can give products a competitive advantage, add value, or extend the life cycle of active ingredients.
Information technologies	• Automation in facilities (greenhouses, storage, etc.) • Data acquisition and analysis • Positioning • Mobile applications • Intelligent sensors	Information technologies can result in improvements in resource and water management; improvements in monitoring soils, weather, and markets; traceability and food safety; and better logistics and quality management.
Equipment	• Automation • Flexible devices • Robotics for homogeneous tasks	Cutting-edge equipment can deliver greater productivity and autonomy.
Food safety	• Monitoring of pathogens • Risk management • Analysis of consumer requirements	Food safety technologies can ensure compliance with regulatory requirements and niche-market demands.
Processing	• Quality improvement • Functional ingredients • Efficient resource and energy management	Better processing techniques can result in an improvement in product properties, shelf-life. and presentation.
Packaging	• Use of active materials for packaging • Sensors and indicators • Radio-frequency identification (RFID)	Packaging can improve product shelf-life and appearance and enhance food safety.
Biotechnology	• GM plants and animals • Molecular breeding • Improved enzymes, yeasts, and bacteria for processing	Biotechnology can improve yields, reduce costs, improve quality, and provide better quality-control and safety systems.

Source: Authors, based on Abrol and Shankar, 2014; Bechar and Vigneault, 2017; Lee et al. 2015; Lehmann, 2012; and Magaña, 2014.

Note: * Herbicide safeners selectively protect crop plants from herbicide damage without reducing activity in target weed species.

in innovation in the agri-food sector. According to the OECD, governments implement policies and regulations that affect the business and innovation environment (tax and agricultural policies, for example). Other actors involved in the innovation process are brokers, input suppliers, markets, and consumers.[5]

Suppliers, who can be considered the first of the direct actors in the chain, include suppliers of seeds, fertilizers, crop protection, gene-modifying technologies, machinery, equipment, veterinary vaccines, probiotics, information technology, and energy. They are connected by networks to producers or agriculture firms that work in agriculture, livestock, and fisheries and aquaculture. These producers are in turn connected to agro-industrial firms that provide processing, packaging, storage, and conservation services. Distributors and brokers then provide traders, storage services, and distribution agents. Finally, local and export markets service retailers, consumers, and export/import agencies. Underlying all these elements are financial services, which include development banking, commercial banks, public funds, international cooperation (international research centres, such as the International Maize and Wheat Improvement Center), and multi-lateral aid.

Over all these direct actors is the regulatory and policy framework, which establishes incentives and 'rules of the game' that also have an influence because they set the environment for firms' activities. External sources of innovation include public and private research organizations, extension services, international research centres, technology brokers, universities, and technology transfer offices. These external actors supply important knowledge-based services to support innovations along the value chain.

Sources of innovation for the agri-food sector

Because of the complexity of the agri-food value chain, many technological inputs are used to support innovation. A review of recent advances is presented in Table 1 to illustrate the diversity of technologies impacting different activities of this industry.

Table 2: New plant breeding techniques

Technique	Purpose
Sequence-specific nuclease (SSN)	Facilitates precise insertion and editing of genes through mutation or replacement
Oligo-directed mutagenesis (ODM)	Introduces a similar sequence that can be used as pattern to repair differences
Cisgenesis and intragenesis	Uses genes of the same species to induce new traits in specific crops
RNA-dependent DNA methylation	Induces transcriptional silencing of genes
Reverse breeding	Provides a precise method of producing hybrids
Agro-infiltration	Uses Agrobacterium as a tool for the temporary expression of genes in plant tissues
Grafting on genetically modified (GM) rootstock	GM rootstocks can be used for improving performance of non-GM scions
Genomics or synthetic biology	Implies the introduction of multiple genes to modify metabolic paths
Induced early flowering	Transgenic early-flowering F1 seedlings are backcrossed in year 2 with another line

Source: Authors, based on Schaart et al., 2016.

The wide range of innovations introduced to this sector meets the requirements of a new competitive environment. The main drivers for efficiency in the agriculture and agri-food industry relate to increased pressure by customers on suppliers for sustainably produced products, as well as competitive pressure that triggers the need to reduce costs and the desire to expand into new export markets, which in turn implies complying with international food safety and health regulations.

Biotechnology innovations for agri-food

A set of important innovations is based on biotechnology. The phrase 'modern biotechnology' refers to various scientific techniques used to produce specific desired traits in plants, animals, or microorganisms using genetic knowledge. Since its introduction to agriculture and food production in the early 1990s, biotechnology has been utilized to develop new tools for improving productivity in crops such as soybeans, corn, cotton, canola, papaya, squash, potato, and apple that are improved versions of the traditional varieties. In addition, improved yeast and enzymes are used to make different food products through biotechnology.[6]

In the area of agriculture, biotechnology has been used to produce genetically modified organisms (GMOs), thus increasing productivity and introducing plants that are resistant to pests, drought, and contaminated soils. The use of biotechnology has led to an increase in yields and reduced cost in important crops such as maize, soybeans, cotton, and canola. Just recently genetically modified (GM) apples and potatoes have been approved for environmental release and consumption in the United States of America.[7]

The use of biotechnology in processing has brought better quality, safety, and long life to food products. New developments are also expected to bring to light raw materials with specific traits useful to specific processing industries. But modern biotechnology has been undergoing a heated debate about the safety of products that has led to strict regulations and entry barriers in important markets (notably in Europe).

Table 2 presents a classification of new plant breeding techniques that are being developed as a response to that restrictive environment. They include: (1) improved plants that contain a new DNA fragment (usually a new gene); (2) improved plants that do not contain a new DNA fragment, but that have a mutation or modification in their own DNA; and (3) improved plants that do not contain a new DNA fragment or any modification of their DNA (such as hybrids).[8]

Biotechnology in Latin America and the Caribbean

Applications of agricultural biotechnology have demonstrated its potential to support improvements in agricultural productivity and the sector's economic growth. However, biotechnology opens new challenges and issues that must be addressed by R&D organizations as well as systems and policy makers.

In Latin America and the Caribbean, the biotechnology industry began to develop in the second half of the 1980s as a consequence of the reduction of barriers that limited foreign investment. The growth of the biotechnology industry was also associated with changes in the laws of intellectual property rights to grant patent protection to biotech inventions and plant breeders' rights to new plant varieties. Patent protection brought confidence to investors, which led to an intensification of research and technology flows.

Research in biotechnology has been supported in different countries in the region, resulting in the development of some new research institutions (universities and research centres). But the creation of biotechnology firms has not been supported to the same degree, so there has been only limited success in building local successful biotech industries. On the other hand, starting in the 1990s, large multinational corporations with large research budgets entered the markets of the largest countries in the region and began to play an increasingly important role as agents of biotechnology diffusion.[9]

As a consequence, even though the land area cultivated with GMOs has grown at an accelerated pace, this expansion has happened only for three crops (soybeans, corn, and cotton), two traits (herbicide resistant and insect resistant, or combinations of both) and eight countries—Argentina, Brazil, Bolivia, Colombia, Honduras, Mexico, Paraguay, and Uruguay—with a large concentration in Argentina and Brazil. Chile has allowed GM plants exclusively for seed production and export. All the GM crops launched commercially in the region have been developed by private multinational firms.

Although important investments have been made in research, no GM product developed by national innovation systems in Latin America has yet been transferred to producers in the region. This reveals that one important problem faced by Latin American innovation systems is the lack of interaction between institutions that generate knowledge and the users of the innovation. A new system of incentives is needed to encourage knowledge generators to embrace diverse demands and propose effective solutions to the problems of producers and companies of different sizes.

This does not mean that technologies have not been produced by the innovation sector in Latin American countries. However, most of the biotechnology innovations produced by the public and private sectors in these countries are conventional applications of biotechnology (tissue culture, fermentation, and the use of molecular tools for breeding).

Countries with a recorded history of investment in human resources as well as innovation and technical change—namely, Argentina, Brazil, Cuba, and Mexico—have an enhanced capacity in terms of the number of techniques used and mastered. There have been some notable achievements in these countries in the development of genomics and some GM crops, but a problem arises in developing commercial applications for those technologies. Countries with an intermediate capacity—such as Colombia, Costa Rica, Chile, Peru, Uruguay, and the Bolivarian Republic of Venezuela—have the capacity to utilize conventional and modern techniques, but their capacities are geographically dispersed and highly concentrated in academic settings. In turn, the rest of the countries in Latin America—Bolivia, Dominican Republic, Ecuador, El Salvador, Guatemala, Honduras, Nicaragua, Panama, and Paraguay—have a poor innovation capacity for conventional biotechnology innovations and even less capacity for modern biotechnology.

Regulatory systems in the region are rather restrictive. Some countries (such as Mexico for corn between 1998 and 2009, as well as Ecuador and Peru declaring moratoria for planting all GM crops) have declared moratoria on the use of GM plants in their agriculture. Such precautionary measures have proven to be ineffective because these countries import GM food products, but they erect barriers to the environmental release of seeds. This has established obstacles to the development of locally modified plants, which demotivates investments in innovation. There is an intense debate in Mexico about GM food production and its impact on the environment and the population. Thus it is necessary to strengthen the study of GMOs through multidisciplinary and committed work that can objectively demonstrate the challenges and feasibility of this type of production.

Regarding research, regional institutions working on agricultural biotechnology in Latin America cover a wide range of techniques, crops, and productivity limitations. This range reflects the wide diversity of genetic resources in the region and the notable efforts made by the research systems and organizations to address strategic regional and national crops and traits.

This diverse innovation portfolio has, however, led to a dispersion of efforts mainly because no concurrent significant increase in the level of human and financial resources is in place. Countries need to set priorities to focus their efforts and resources towards feasible programmes with stronger ties to farmers and firms.

In terms of the environmental and food safety evaluations needed to commercialize GM products, most countries require improvements to their regulatory bodies and oversight mechanisms. Even in those countries with an existing critical mass of mechanisms (institutions, regulations, infrastructure) to ensure biosafety, social and political pressures have caused the dissemination of technologies approved by the biosafety regulatory authorities to slow.

A faster response from regulatory authorities is required, because a poor capacity to conduct biosafety assessments, strongly influenced by the lack of political will to implement modern biotechnology applications, is demotivating investment by public and private sectors to boost R&D and biotechnology diffusion. Even if the institutional framework is complete, it is essential to assume that a major overhaul of the organization of the structures will be required for its implementation—the framework is currently extremely complex and bureaucratic, which contributes to the uneven diffusion of its benefits, since only a few actors have the qualifications to manage innovation in this environment.

In the case of intellectual property management, countries such as Argentina, Brazil, Chile, and Mexico make use of instruments and negotiation capacity. However, the highest shares of intellectual property protection instruments in these countries are held by non-residents. This suggests that more effective incentives for creative processes should be implemented. In most Latin American countries, agricultural research has taken a very academic route. The indicators are telling: while production of scientific articles has solidly increased in the last 10 years, the generation of intellectual property and effective technological solutions for producers represents a very small percentage of research results.

This relative scarcity of innovative solutions is the consequence of an incentive system for researchers that emphasizes academic production and sidesteps problems in the sector. More technologies are now urgently needed for the efficient use of water to improve land, correct pollution problems, increase production yield, and improve comprehensive farm management.

Moreover, a lack of reliability and quality of supplies means that successful industries resort to imports or to large local suppliers to obtain their supplies. No effort is made to develop new suppliers, which would generate market incentives to improve production. This is an opportunity for innovators.

Technological innovations are systematically incorporated by commercial agriculture producers, who resort to technological resources in other countries. They also turn to these other countries for technical support as well as for machinery, agrochemicals, and seed suppliers. Some local producers work by contract to export vegetables, and their relationship with a broker or their customers in the importing market gives them access to technological packages supplied by sales companies that act as intermediaries. In both cases, links with domestic institutions are scarce.

In some countries, public and some private financial organizations have various support schemes for farmers and companies, but they do not have effective instruments to finance technology development projects, create new businesses, or adopt technology. The requirements of these organizations often exclude a wide range of producers (small farmers), which can widen performance gaps.

A sound innovation policy requires that shared socioeconomic objectives provide the motivation for better articulation of the innovation system and the space for designing more effective policy instruments than what now exists.

The formulation of policies that raise the public's confidence and that successfully insert useful and sustainable biotechnology innovations will be a major challenge that countries in Latin America and the Caribbean will face in the near future.

Challenges for agri-food biotechnology innovations: The case of Mexico

Mexico is equipped with knowledge and expertise in agricultural biotechnology—it has important research facilities at universities such as the National University of Mexico, the Center for Research and Advanced Studies of the National Polytechnic Institute, and the Metropolitan Autonomous University, as well as public research centres such as the Center for Research and Assistance in Technology and Design of the State of Jalisco; the Yucatan Center for Scientific Research; and the National Institute of Forestry, Agriculture and Livestock Research. Mexico also has regulatory systems in place to assess biotechnology products according to the country's Biosafety of GMOs Law. However, Mexico is at crossroads as a result of negative perceptions of GMO technology, including fears about the environmental impacts of genetically engineered crops that some opponents have spread among some sectors of society. This has erected additional barriers to new investors, and the number of Mexican biotechnology firms is low and concentrated in applying traditional techniques (fermentation, use of enzymes, tissue culture, and molecular breeding).

The most important GM crop produced in Mexico is cotton, which covers more than 90% of the planted area in the country. It is a success story because the use of chemical pesticides has been reduced by more than 50% and important cost advantages have been brought to producers.[10]

The second GM crop that has reached commercial release in Mexico is soybeans. Permits were granted in 2012 for production on 253,500 hectares. However, Mexican honey producers have expressed great concern, particularly since the European Court of Justice ruled that honey—which contains trace amounts of pollen from genetically engineered crops authorized for human consumption in the European Union—must be labelled if the amount of genetically engineered pollen surpasses 0.9%. Because of this ruling, all honey shipments from Mexico must undergo laboratory testing to identify and quantify the type of genetically engineered presence.[11]

The Mexican government was about to grant permits for the commercial planting of GM corn in very specific areas that are distant to fields considered centres of origin and diversification for the crop. In September 2013, a federal judge responding to a legal action initiated by a consortium of activist groups effectively suspended the plantings of all GM corn in Mexico by placing a provisional injunction. After four years it is still not clear whether those permits will be granted. This lack of clarity is an obstacle not only for the commercial use of seeds developed by multinational firms but also for technologies generated by Mexican research groups.

This discussion highlights the role of institutions and policies in the diffusion and generation of new biotechnological innovations. It also shows that emphasis has to be given to the transfer of knowledge to commercial firms because they are a key factor in the development of agri-food biotechnology. Countries in Latin America and the Caribbean need new policies aimed not only at strengthening research capacities but also at translating research results into viable biotechnologies to solve some of the critical problems of agriculture.

Conclusions

Research capacities created in Latin American countries need to translate into actual solutions to the problems of the agri-food sector. In order to achieve this goal, a new system of incentives is necessary to encourage knowledge generators to embrace diverse demands and propose effective solutions to the problems of producers and companies of different sizes.

Although the institutional framework that is essential for regulating new technologies, such as innovations in biotechnology, is complete, it still needs a fundamental overhaul of its structure so that it can be implemented. Currently the institutions are so complex and bureaucratic that only a few actors—primarily multinational firms—have the qualifications needed to navigate the system. The result is that the framework, instead of helping to diffuse the benefits of new technologies through all levels of the sector, ends up ensuring that their diffusion is uneven.

Innovation policy requires that shared socioeconomic objectives, such as those related to sustainability and more equitable development of the agri-food sector, provide the motivation for a better articulation of the innovation system and increasing the space for designing more effective policy instruments than now exists.

Notes

1 Moreddu, 2016.

2 Costa and Jongen, 2006.

3 The *Oslo Manual* defines innovation as the implementation of a new or significantly improved product (good or service) or process, a new marketing method or a new organizational method in business practices, workplace organization or external relations (OECD and Eurostat, 2005).

4 OECD, 2013.

5 OECD, 2013, p. 13.

6 Food Insight, no date, available at http://www.foodinsight.org/Background_on_Food_Biotechnology.

7 To get a more precise view on biotech innovations, a review was conducted of recent biotechnology patents (2011–2017). There were 736 identified patents. The leading inventors are Monsanto Technology LLC, Pioneer Hi Bred Int., BASF Plant Science, Du Pont, and Syngenta. Together these firms have more than 50% of the patent files, which is an indicator of the high level of concentration of innovation.

8 Schaart et al., 2016.

9 Otero, 2008.

10 Solleiro et al., 2014.

11 Mexican honey producers filed a court injunction against the approval of GE soybeans for commercial production. This has led to a long legal procedure and the judge has ordered a temporary suspension of the permits arguing that the public consultation of the local communities was not adequate. 'As a result of this issue, approximately 15,000 hectares were not planted to GE soybeans in 2012 and there have been no more applications for commercial or pilot releases of GE soybeans during 2013 to 2015' (USDA FAS, 2015, p. 5).

References

Abrol, D. P. and U. Shankar. 2014. 'Pesticides, Food Safety and Integrated Pest Management'. In *Integrated Pest Management: Pesticide Problems, Vol. 3.,* eds. D. Pimentel and R. Peshin. Springer Netherlands: 167-199.

Bechar, A. and C. Vigneault. 2017. 'Agricultural Robots for Field Operations. Part 2: Operations and Systems. *Biosystems Engineering* 110–28.

Costa, A. I. A. and W. M. F. Jongen. 2006. 'New Insights into Consumer-Led Food Product Development'. *Trends in Food Science and Technology* 17: 457–65.

Food Insight. No date. 'Background on Food Biotechnology'. Available at http://www.foodinsight.org/Background_on_Food_Biotechnology.

Lee, S. Y., S. J. Lee, D. S. Choi, and H. S. Jin. 2015. 'Current Topics in Active and Intelligent Food Packaging for Preservation of Fresh Foods'. *Journal of the Science of Food and Agriculture* 95 (14): 2799–810.

Lehmann, R. 2012. 'Future Internet and the Agri-Food Sector: State-of-the-Art in Literature and Research. *Computers and Electronics in Agriculture* 89: 158–74.

Magaña, S. C. 2014. Desarrollo de equipos, sensores e instrumentos para agricultura de precisión y labranza de conservación. Lecture presented at the ceremony to grant the Premio Innovagro (Innovagro Award), 24 April 2014, Cordoba University, Spain.

Moreddu, C. 2016. 'Public-Private Partnerships for Agricultural Innovation: Lessons from Recent Experiences'. *OECD Food, Agriculture and Fisheries Papers* No. 92. Paris: OECD Publishing. Available at http://dx.doi.org/10.1787/5jm55j9p9rmx-en.

OECD (Organisation for Economic Co-operation and Development). 2013. *Agricultural Innovation Systems: A Framework for Analysing the Role of the Government.* Paris: OECD Publishing. Available at http://dx.doi.org/10.1787/9789264200593-en.

OECD and Eurostat (Organisation for Economic Co-operation and Development and Eurostat). 2005. *Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data,* 3rd Edition. Paris: OECD Publishing.

Otero, G. 2008. 'Neoliberal Globalism and the Biotechnology Revolution: Economic and Historical Context'. In *Food for the Few. Neoliberal Globalism and Biotechnology in Latin America,* ed. G. Otero, ed. Austin: University of Texas Press, 1–29.

Schaart, J. G., C. C. Wiel, L. A. Lotz, and M. J. Smulders. 2016. 'Opportunities for Products of New Plant Breeding Techniques'. *Trends in Plant Science* 21 (5): 438–49.

Solleiro, J. L., O. Díaz, and C. Gaona. 2014. Análisis de la cadena de valor en la producción de algodón en México [Analysis of the Value of Chain in Cotton Production in Mexico]. Mexico: FAO. Available at http://docmia.es/d/98572.

USDA FAS (United States Department of Agriculture, Foreign Agricultural Service). 2015. *Agricultural Biotechnology Annual Mexico.* Mexico City: US Department of Agriculture. Available at https://www.fas.usda.gov/data/mexico-agricultural-biotechnology-annual.