Food and Nutritional Security in Mexico: Major Challenges for the Twenty First Century

Family from Quintana Roo and a sample of the enormous diversity of foods found in the market. Many Mexican families supplement their diet with food planted for on-farm consumption. Photography © Fulvio Eccardi

Mexico

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Mexico is rich in natural and human resources, but owing to a complex topography has limited arable land. **Mexico is now a net food importer, dependent on other countries for food security** and vulnerable to climate change, especially in desert and coastal regions. **Scientific and technological institutions are very good, but further investment is needed** as well as a closer linkage between public and other agricultural sectors. Evidence-based public policies will be more important than ever in combatting these challenges

Summary

Mexico is the thirteenth largest country worldwide. It has enormous environmental heterogeneity, due to its physiographic complexity, intricate geological history and varied climates. It also has vast cultural wealth due to its indigenous peoples, who have interacted for thousands of years with the country's vast biological diversity. This interaction has resulted in the description of 5,500 species of useful plants, and the domestication of over 200 species of economic importance. Cropland accounts for 55% of Mexico's total area, while 14% corresponds to arable land, limited by both dry climates and the steep slopes of its terrain. In terms of food and nutrition security, Mexico ranks 15th in the Food Sustainability Index and tenth in Sustainable Agriculture (Food Sustainability Index, 2016), and therefore still has significant areas of opportunity to meet the challenges of the next 50 years. The country has vast natural resources, diversified agricultural capacity, operational institutional infrastructure and competition in scientific, technological and innovation development. There are state policies focused on addressing the main problems of agriculture, nutrition and the environment. However, these are usually implemented in piecemeal fashion and with little continuity, under an incipient transversality scheme.

The major challenges facing the nation for its food and nutrition security require the coordination of various sectors and actions aimed at implementing strategies for adaptation and mitigation of climate change. These challenges require the strengthening of programs for the conservation and sustainable use of biodiversity and genetic resources. There is also an urgent need to boost effective investment for the development of the countryside through alliances between the public and private sectors and academia, in order to generate innovations that meet the needs of the various strata involved in food production.

I. National characteristics

a. Physical size, inventory of arable land, environmental and landscape heterogeneity

Mexico is located in the northern hemisphere of the American continent, with most of its territory in North America and the rest in Central America. It has coasts in both the East – the Gulf of Mexico and the Caribbean –and the West - Pacific Ocean and Gulf of California–. Mexico has 1,959,248 km² of mainland and 5,127 km² of islands, comprising a total area of 1,964,375 km². Its maritime area covers 5,109,168 km² corresponding to the patrimonial sea (territorial sea, contiguous zone and exclusive economic zone).

Mexico's agricultural land accounts for 55% of its total area, whereas its arable land is limited by both the dry climate and the steep slopes accounting for 14% of its total territory (World Bank, 2016). According to the National Agricultural Survey (ENA 2014, SAGARPA-INEGI), the total agricultural area of the production units is 27.5 million ha, equivalent to 25.2% of a total of 109.3 million ha. The remaining 81.8 million haa correspond to the area of summer pastures (for cattle), farmland or fallow land.

Mexico has enormous environmental heterogeneity, due to its physiographic complexity and intricate geological and climate history. The physiography of Mexican territory is the result of the interaction of five tectonic plates: North American, Pacific, Rivera, Cocos and Caribbean (Ortega et al., 2000). Their joint action has created seven mountainous systems, two large coastal plains and a plateau. Moreover, the funnel shape of Mexican territory -broad in the North and narrow in the South-, the mountain systems that converge in the South and the SE, the action of the trade winds and the seasonal oscillation of the subtropical high pressure belt contribute to a diverse climate pattern, so that all climates are represented in the country (Vidal-Zepeda, 2005): from very dry in the North, sub-humid and extremely humid in the South, to cold in the mountain peaks (>4,000 m altitude) (Espinosa et al., 2008). Additionally, due to its geographical position, Mexico is regarded as the border zone between the Neoarctic and Neotropical biogeographic regions. This transition permits the flow of species from one region to another (Luna-Vega, 2008), all of which results in an increase in the diversity of taxa present in the country.

b. Demographic characteristics and future trends

According to the results of the Intercensus Survey of the National Institute of Statistics and Geography (INEGI, 2015), Mexico has a total population of 119,530,753 inhabitants, with an annual growth rate of 1.4%. According to the population projections of the National Population Council (CONAPO) 2016, Mexicans have a life expectancy of 75.2 years.

The 2015 population pyramid is wider in the center and narrower at the base, meaning that the proportion of children has decreased while that of adults has increased. In 2015, the population under 15 accounted for 27% of the total, the 15-64 age group 65% and the elderly population 7.2%, **Figure 1** also shows the proportion of men and women.

This situation indicates that the population of working age is more important in relative terms, which translates into an opportunity for economic growth for Mexico. This is what has been called the demographic bonus, which happens when the volume of people of working age is greater than the number of economic dependents; thus, families can save more or productive investment can increase considerably, although there must be an economic context that favors this. In this respect, the use of the demographic bonus requires meeting various requirements,

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including, for example, prior investment in education, adequate structures to incorporate all these people into work and working conditions that ensure the stability needed to encourage savings. Some demographic specialists believe that unless this is done soon, Mexico will lose the opportunity to take advantage of this demographic bonus. They also warn of the need to take advantage of the gender bonus, in other words, to incorporate a higher percentage of women into the labor force (Alba et al., 2007; Giorguli, 2016).

c. Farming Modalities

Of the 27.5 million ha of agricultural land, 81.5% correspond to land that has been sown or planted, and the remaining 18.5% to non-cultivated land. According to the Agro-Food and Fisheries Information Service, a total of 21,938,184 ha (SIAP, 2016a) were planted in 2016.

Of the agricultural area, 20.3% is under irrigation (5.6 million ha) while the remaining 79.7% is rain-fed (21.9 million ha). The results of the ENA (2014) indicate that 66.3% of production units under irrigation with an area of between 0.2 and 5 ha occupy 14.3% of the agricultural area, while 31.3% of the units with more than 5 ha (commercial) cover 85.6%. As for rain-fed production units, 70.5% of those that measure up to 5 ha (self-consumption) occupy 20% of the agricultural area, while 6.1% of those with more than 20 ha (commercial) cover 49.9%. According to the Diagnosis of the Rural and Fisheries Sector carried out in 2012 (FAO-SAGARPA, 2012), agricultural production units are classified into six strata as shown in **Table 1**, so that profitable, dynamic, highly-technified units coexist alongside small producers, who tend to have areas of less than 5 ha with low productivity.

In Mexico, the use of improved seeds is not widespread among producers, since only 29% of production units use them, whereas 82% use criollo seeds. However, it is important to note that, in terms of area, 68% of the area planted with annual crops uses improved seeds. Only 0.2% corresponds to transgenic seed.

Figure 1. Population Pyramid 2015 (INEGI, 2015)

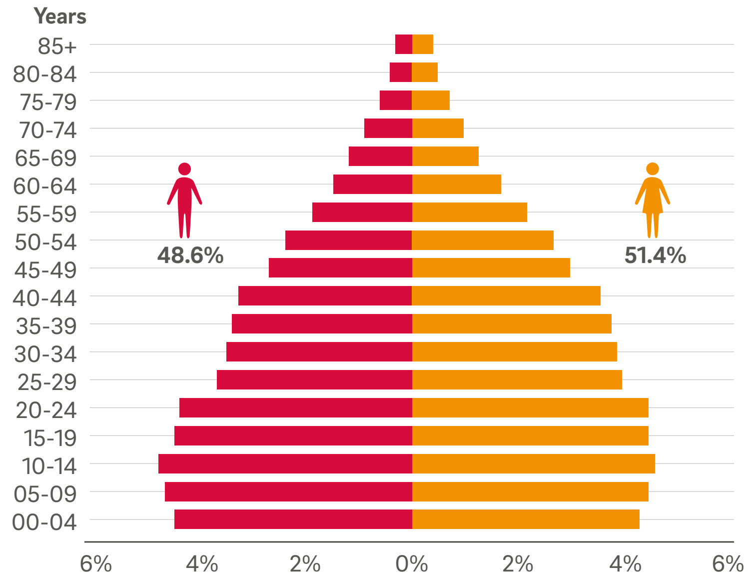


Table 1. Classification of Productive Agricultural Units (PAU) in Mexico

	Type	Number of Units	%
E1	Non-market family agriculture	1,192,029	22.4
E2	Family agriculture linked to the market	2,696,735	50.6
E3	In transition	44,370	8.3
E4	Unprofitable commercial agriculture	528,355	9.9
E5	Thriving commercial agriculture	448,101	8.4
E6	Dynamic commercial agriculture	17,633	0.3
	Total	**5,325,223**	**100**

i. Major Food Crops

Mexico also has enormous cultural wealth due to its indigenous peoples, who have interacted for thousands of years with the country's vast biological diversity. This interaction has resulted in the description of 5,500 species of useful plants (Caballero and Cortés, 2012), and the selection and modification (domestication) of over 200 species (Casas et al., 2007). The historically most important species were beans, chili, squash and mainly maize, whose domestication and genetic improvement are activities that probably date back over ten thousand years (Miranda-Colín, 2000).

Mexico's most important crop is maize with its 64 strains or native varieties (Sánchez et al., 2000) and numerous improved varieties. It is mainly planted in tropical sub-humid, temperate humid and sub-humid zones (Fernández-Suárez et al., 2013). In 2014, the area under maize was 7.4 million hectares (ha), 82.5% of which is rain-fed. Production for that year stood at 23.13 million tons (t). Although irrigated land accounts for only 17.5% of the total area under maize, average yields per ha are considerably higher; in land under irrigation, it was approximately 8.0 t/hectare (ha), whereas in rain-fed crops, the average was 2.3 t/ha (FIRA, 2015).

As for other agricultural products, in 2015, production of the 52 main crops was 4.7% higher than in 2012, mainly due to increases in fruit crops (14.4%), agroindustrial crops (7.9%), vegetables (11.6%) and grains (2.3%). The following increases were recorded by crop: rice (13.3%), corn (11.9%), asparagus (66.1%), broccoli (34.1%), lettuce (30.3%), onion (100%) and sugar cane (11.3%, SAGARPA, 2016a). Among annual crops, in addition to corn, the main crops were: beans, sorghum, wheat, barley, cotton and chili. The main perennial crops include: coffee, sugar cane, orange, alfalfa, mango, lemon, avocado, banana and cacao (ENA, 2014).

ii. Livestock production

Mexico produces cattle and goats (for milk and meat), pigs and sheep (for meat), poultry (for meat and eggs) and bees (for honey). Livestock production also includes aquaculture (fish farming) and rabbit breeding.

In 2015, record meat production was achieved with 6.2 million tons (in carcasses), equivalent to 276,000 t (4.6%) more than in 2012, due to the increase in pig farming (6.8%), poultry (6%) and cattle (1.3%). There was also a significant increase in the amount of egg, milk and honey obtained (14.5, 4.7 and 5.1%, respectively), and in aquaculture production (11% from 2014 to 2015). For all of the above, Mexico has positioned itself as a major producer of animal protein in the world, occupying seventh place (SAGARPA, 2016a).

d. Is the country self-sufficient in agriculture?

Food security has always been a priority in Mexican state policies. However, year after year, food security is extremely vulnerable to variations due to the climate, domestic agricultural policy and international economic conditions.

Mexico had been a net exporter before the 1980s, becoming a food and product importer in the late 20th century. From the mid-1990s to 2008-2010, agricultural imports increased by 201%. Self-sufficiency for maize, wheat, soybeans, cotton, rice, pork, beef and chicken has declined in recent years (UNCTAD, 2013). It was not until 2015 that a positive trade balance for agricultural exports was achieved (SIAP, 2016).

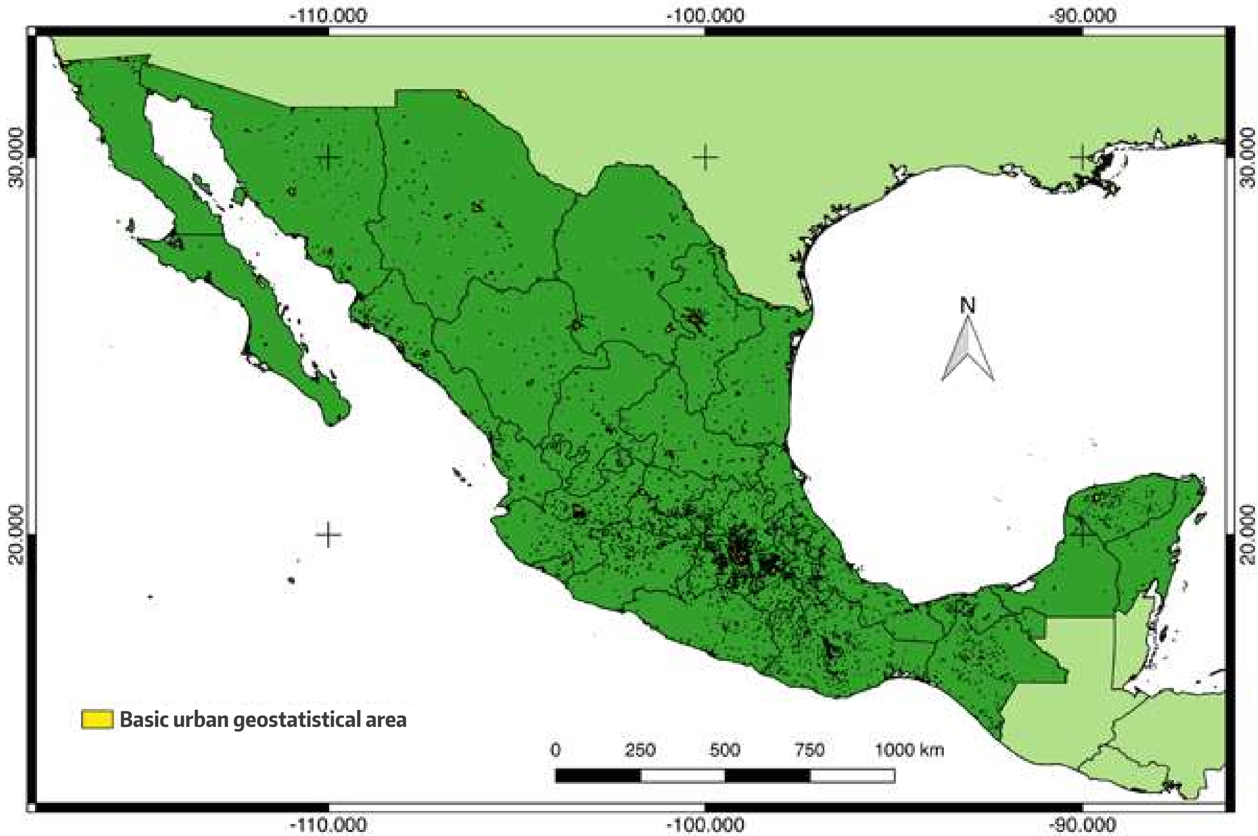
The agrifood trade balance reported by the Secretary of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA) in 2015 indicates a surplus balance for Mexico. The main export products, in which the country is self-sufficient, are vegetables and fruits with 28% and 25% of the total export value (mainly tomato, cucumber, lime, avocado, chili, strawberries and berries, banana and watermelon). However, the country has a deficit of cereals, meat, seeds and oilseeds, which are imported mainly from the U.S. (SAGARPA, 2016b).

Domestic production of white maize - intended for human consumption - is considered sufficient to meet national demand. Per capita maize consumption in Mexico is approximately 10 times that of the U.S. (Serna-Saldivar and Amaya-Guerra, 2008), and in 2014, over 23.13 million t of maize were produced (FIRA, 2015). However, the production of yellow maize - mainly used as fodder and in industry - is insufficient. On average, more than 10 million t are imported annually, mostly from the U.S. (FIRA, 2015). The same happens with the soybean consumed in the country, since 91.9% is imported, representing about 3.9 million t destined for animal nutrition.

e. Trends in urbanization

In Mexico, urban growth involving changes in the area, population and density of cities can be described in three stages: 1) from 1900 to 1940, it was characterized by a strong rural predominance and relatively slow urban growth; 2) from 1940 to 1980, there was a rapid shift

Figure 2. Map of Mexico showing the territorial extension of urban localities (urban basic geostatistics area, constructed on the basis of INEGI, 2016)



to urban predominance with high levels of concentration; and 3) from 1980 to present, there was more moderate and diversified urban growth within the country (CONAPO-SEDESOL, 2012). The urban population is distributed among a set of 384 localities, comprising the National Urban System (SUN), varying in size and scope from small cities (between 15 and 99 thousand inhabitants) through intermediate cities (between 100 and 999,000 inhabitants) to large ones (one million or more inhabitants) (Sobrino, 2011).

Whereas in 1950, just under 43 per cent of the population lived in urban localities, in 1990, this percentage had increased to 71 per cent, and by 2010 almost 3/4 of the population (more than 86 million) lived in one of the cities comprising the National Urban System (**Figura 2**; Islas-Rivera et al., 2011). Mexico has obviously moved from being a rural and agrarian country to a predominantly urban one, through the demographic growth of cities due to the migration of the rural and indigenous population to large and intermediate cities (Rosas-Rangel, 2009).

f. Impacts of migration

Mexico has seen the massive displacement of rural labor to its cities and the U.S.. It is estimated that between 1990 and 2002, the Mexican rural population working in the U.S. increased from 7% to 14% (Mora et al., 2005). Rural migration has also increased. In 1995, the flow of people recorded by the Survey on Migration on Mexico's Northern Border (EMF-North) was 276,800, whereas in 2007, it was 542,100 (historical maximum at 12.6 million), decreasing to 328,300 people because of the U.S. crisis. According to estimates by the Pew Hispanic Center (PHC), there are currently 11.1 million Mexican migrants (Arrazola-Ovando and López-Arévalo, 2012).

Migrant agricultural workers are usually over the age of 30 and have low educational attainment. Most choose agriculture as a labor niche, since they lack English-language proficiency and, in some cases, have a poor command of Spanish – due to the growing participation of the indigenous population, mainly from the state of Oaxaca - and because they already have a certain level of specialization in agricultural activities. There are more male than female migrants, partly because of the tightening of U.S. migration policies (Zúñiga-Herrera, and Arroyo-Alejandre, 2006), while women who migrate are mainly hired to perform cleaning and housework activities (Rojas-Rangel, 2009).

These migratory flows (from the countryside to the cities or abroad) modify the dynamics of migrants' rural communities of origin. For example, women's access to land ownership has been increasing as a result of men's migration (SIAP, 2016). At best, migration can contribute to improving the living conditions of sending communities through the use of remittances and knowledge transfer (which the migrant provides to the community). However, when migration continues for longer periods, it can deprive rural areas of labor and lead to the loss of skills (Chávez and Campos, 2013).

g. Main export/import crops and markets

According to the Agri-food and Fisheries Information System (SIAP), Mexico is one of the countries that export the most agricultural products. Due to their variety and quality, agrofood exports generated an income of $26.714 billion USD in 2015, surpassing the revenue created by remittances, oil exports and foreign tourism. Moreover that same year, exports exceeded imports due to a positive trade balance of $960 million USD, not seen for 20 years.

The main exports are divided into four categories:

1. Agroindustrial: These correspond to 51.4% of exports. This classification includes products such as confectionery, tequila, beer, bread, chocolate, preserved fruits, sugar and fruit juices.
2. Agricultural: These account for 40.9% of exports, including avocado (Mexico is the world's leading avocado producer), tomato, cucumber, lime, chili, strawberry, zucchini, banana, blackberry, onion, watermelon and raspberry.
3. Livestock and beekeeping: These account for 4.3% of exports and include products such as pork, beef and honey.
4. Fish: These account for 3.4% of exports and include lobster, shrimp, tuna, sardine, crab and oyster.

The main countries to which Mexico exports its products are: U.S., Japan, Canada, Guatemala, Venezuela, Netherlands, the United Kingdom, Germany, Spain and Colombia. A network of 11 free trade agreements with 45 countries gives Mexico a potential market of 1,462 million people, which encourages the search for new opportunities and better conditions for sales of agricultural, livestock and fishing products.

Mexico imports an average of over 10 million t of maize annually (FIRA, 2015). In 2015, imports of this grain stood at 11.97 million t. Moreover, that same year, the country also imported other products such as wheat (4.2 million t), soybean (3.9 million t), paddy rice (876 thousand t), pork (750 thousand t), chicken meat (481 thousand t), apple (310 thousand t), grain sorghum (220 thousand t), barley (168 thousand t) and grain oats (142 thousand t). Imports mainly come from the U.S., China, Canada, India, Brazil, Argentina, Russia and Australia (SIAP, 2016).

h. Main agricultural challenges

The main problem of Mexico's agricultural sector is that it has not been developed in a sustainable manner. This is a consequence of the low growth in agricultural and fishing activity, the persistence of rural families' poverty, the degradation of natural resources in the sector, the unfavorable economic environment and the existence of a weak institutional framework to create policies that will contribute to the development of the sector. There is a low development of technical-productive and entrepreneurial capacities. This is compounded by poor technological innovation and limited funding for agricultural and fisheries activities. The economic environment is unfavorable, with distorted international prices and limited access to markets (FAO-SAGARPA, 2012).

In 2016, the United Nations Summit on Biological Diversity was held in Mexico. As a result of the high-level segment, the Cancun Declaration was adopted, which recognizes the importance of integrating biodiversity into different sectors of human activity. For the agricultural sector, COP-13 recognized the importance of biodiversity for food security, human nutrition, health and well-being, as well as its contribution to ecosystem processes and climate change mitigation.

II. Institutional environment

a. National Agricultural Research Systems

Mexico has a research and development system that can be divided into infrastructure for basic (or free) research and applied (or directed) research, as well as training programs in agronomy, agriculture and biotechnology, from the technical level to postgraduate programs in basic and applied aspects. SAGARPA has support programs for research and technological development projects that help both academic institutions and firms. SAGARPA also has an education and research system comprising the National Institute of Forestry, Agriculture and Livestock Research (INIFAP), eight regional research centers, five National Disciplinary Research Centers and 38 experimental fields and a research and postgraduate center (Postgraduate College), which, in turn, has seven campuses in various states and two universities dedicated to the training of human resources at the undergraduate and graduate level: The Autonomous University of Chapingo (UACh) and the Antonio Narro Autonomous Agrarian University.

In addition to the main agricultural research centers mentioned, the country also boasts: the Advanced Agricultural College of the State of Guerrero and the National Fisheries Institute, while the Public Centers of the National Council of Science and Technology (CONACYT) include the Yucatán Center for Scientific Research (CICY). All these institutions plan, organize, generate and transmit scientific knowledge and produce a faculty of professionals, teachers, researchers and technicians who guide the rational, economic and social use of agricultural resources and agro-food technological innovation.

Mexico is also the site of the International Center for the Improvement of Maize and Wheat (CIMMYT), which runs programs to improve these two crops and generate materials adapted to different parts of the world, particularly Latin America and Africa. CIMMYT is probably the only institution in Mexico to implement molecular and genomic markers for genetic improvement.

CONACYT has several funding programs for research projects that support research programs in academic institutions, some of which deal with agronomic and livestock aspects.

It has several sectoral funds, including one with SAGARPA for research and development in agricultural and livestock areas. The Intersecretarial Commission on the Biosafety of Genetically Modified Organisms (CIBIOGEM) also has a program for the development of biosafety and biotechnology that supports the research of Genetically Modified (GM) organisms, including crops.

Although there are various programs to support scientific research and technological development, there is no plan to integrate these programs or establish priority areas and desirable goals for periods of at least 10 years. It is also important to increase the transparency of the mechanisms to provide support, especially those implemented by SAGARPA.

i. Research capacities that require further development

There is an urgent need to strengthen the quantity and quality of breeding programs for plants and animals and increase the number of researchers working in this area who are able to incorporate the new molecular and genomic strategies that hasten genetic improvement. The number of researchers has declined in recent years and programs went from being highly competitive in the 1960s and 1970s, to being uncompetitive and productive in the last two decades, despite certain important yet isolated successes.

Although valuable work has been done in the area of phytopathology at various institutions, these have failed to be translated into effective diagnostic systems for producers. Most analyses are sent abroad or carried out by national commercial laboratories that use diagnostic kits imported from other countries. It is therefore necessary to strengthen research programs in the field of phytopathology not only to detect and characterize the pathogens affecting the country's main crops, but also to develop diagnostic kits that identify and differentiate local pathotypes.

Although Mexico boasts significant human and physical infrastructure in the area of biotechnology, this infrastructure is insufficient for effectively addressing all the problems of the country's main agricultural crops.

The area of animal biology lags significantly behind the agricultural sector, since until lately there were no laboratories working on the most modern of breeding and genetic engineering techniques in livestock species. In 2015, priority was given to the development of research and livestock technology transfer to develop projects such as the Center for Livestock Genomic Reference in Morelia, Michoacán, a benchmark laboratory with state-of-the-art technology in genomics. Its operation is expected to chart a new direction for livestock since its DNA analysis will make it possible to use genomic selection to improve livestock characteristics in a shorter time (SAGARPA, 2016a).

In the area of animal health, there are competent researchers and relevant research projects, yet without programs and schemes to design and produce vaccines for the main animal diseases occurring in the country. Although there are several groups initiating projects using new genomic editing technologies, Mexico must strengthen its programs in this area to take full advantage of the enormous impact they can have on both plant and animal genetic improvement.

ii. Local areas of strength

The most important research centers in molecular biology and plant genomics include the UNAM Institute of Biotechnology and Center of Genomic Sciences; the Irapuato Unit and the National Laboratory of Genomics for Biodiversity (LANGEBIO); the Center for Research and Advanced Studies (CINVESTAV); CICY; the San Luis Potosí Institute for Scientific and Technological Research; and state universities such as the Michoacán University of San Nicolás de Hidalgo, the Autonomous University of Morelos and the Autonomous University of Nuevo León. There are other universities and technological institutes with research groups that do significant work in the area, but these are isolated efforts rather than institutional programs.

Mexico's main strengths are: the study of the molecular biology of development processes in plants, the responses to environmental factors and the link with symbionts, nitrogen-fixing bacteria and mycorrhizae. There are also several leading groups working on the development of biofertilizers and bacteria that promote plant growth, which in some cases have created products marketed by domestic firms. An example of this is Biofábrica Siglo XXI, which commercializes biofertilizers developed at the UNAM Center of Genomic Sciences.

One area in which Mexico is a standout is the genomics of agricultural crops, both in the use of transcriptomic analyses to examine the biological processes of plants in response to adverse environmental factors, and the sequencing and characterization of the genomes of the country's native crops. LANGEBIO in Irapuato, Guanajuato has sequenced the genome of popcorn, the common bean, chili and avocado, among others.

iii. Scientific collaboration networks inside and outside the country

The various research centers in Mexico have collaboration programs at both the national and international level. Many Mexican institutions have collaboration agreements, mainly with American and European institutions. In agriculture, the UC-Mexus program grants scholarships and donations for collaborative research between researchers from Mexican institutions and those at various University of California campuses, as well as a number of collaboration programs through CONACYT agreements with American and European universities that provide funds for reciprocal visits in order to establish collaboration programs.

CONACYT's Thematic Networks promote interdisciplinary collaboration to address complex problems in issues of national interest in a coordinated fashion among academia, government and society. These networks bring together people interested in working together to address a key national problem. Each network is collegially coordinated by a Technical Academic Committee (CTA) in five main areas: Environment, Knowledge of the Universe, Sustainable Development, Technological Development, and Energy, Health and Society. Since 2017, the activities of CONACYT's 27 Public Research Centers have been reoriented to form 10 research and industrial development consortia, some of which focus on the agri-food sector (Adesur-Acapulco for the agri-food industry, Agro-Hidalgo, Pachuca oriented towards research and development, Intel-Nova, Aguascalientes and Mérida). There are expected to be 18 consolidated consortia by 2018.

iv. Access to and maintenance of databases for monitoring farming systems

SIAP, a decentralized body of SAGARPA, is responsible for the collection, integration, sampling, quantitative evaluation, organization, analysis and dissemination of statistical and geospatial information on the agri-food sector, in accordance with applicable legal provisions, as well as integrating and updating the corresponding documentary collection. It provides the population with a platform for browsing these databases. SAGARPA also promotes the use of technology through applications to document the information derived from agricultural activities, for which it has designed free-access applications on mobile devices that facilitate access to information in the sector.

b. Universities and Research Institutes

i. Scientific development and infrastructure

As for research infrastructure in Mexico, the most competitive research centers in the country have equipment and facilities similar to those of American or European institutions. CONACYT has a support program to strengthen research centers through the acquisition of state-of-the-art equipment or platforms, including the purchase of DNA sequencers, microscopes and mass spectrometry equipment.

ii. Inter- and transdisciplinary research capacities, modeling

This infrastructure, together with the training of personnel at doctoral and postdoctoral level abroad, has permitted the continuous development of the country's scientific capacities. However, Mexico has approximately 30,000 researchers registered, a very small universe for a country of 120 million inhabitants, particularly in comparison with the number of scientists per thousand inhabitants in developed countries. This means that there is an urgent need to promote the creation of new research and technological development centers to incorporate young people who are being trained at the master and doctoral level, at both national and foreign institutions, so that they can develop their capacities in an environment that encourages transdisciplinary research, an aspect that is still only marginally developed. There are also several universities and technological institutes in the country offering degree programs in agronomy, zootechnics and biotechnology.

c. Development of a trained workforce and the state of national educational systems

Mexico offers dozens of master and doctoral programs in agricultural and biotechnological specialties, including some that are internationally competitive, such as those offered by the UNAM Biotechnology Institute, CINVESTAV plant biotechnology in Irapuato, CICY and those of the San Luis Potosí Institute for Scientific and Technological Research. More traditional programs, but also of excellent quality, are offered by the College of Graduates, and the Autonomous Universities of Chapingo and the Antonio Narro University. Over 150 master and doctoral students graduate in these areas every year.

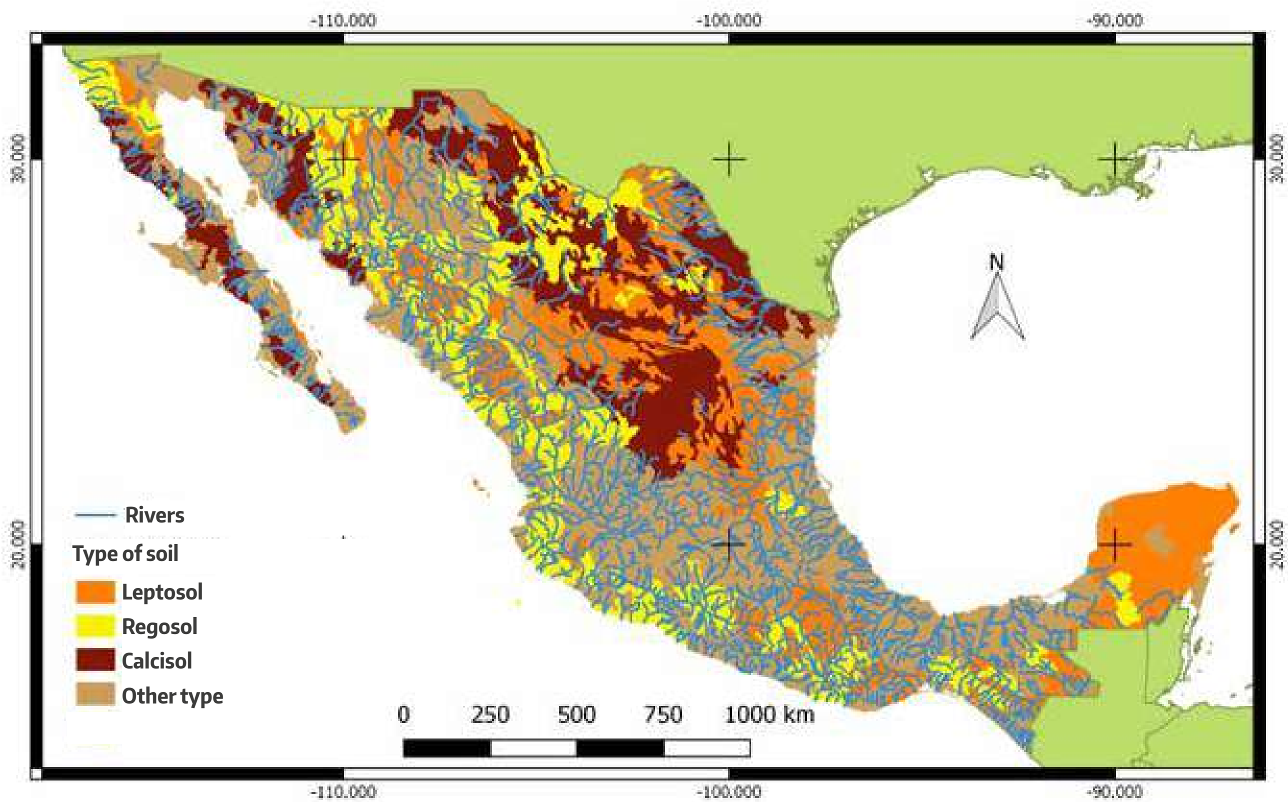
d. Contributions of the public and private sectors

Very few Mexican companies in the field of agriculture or agricultural biotechnology have their own research programs. National seed companies have their own breeding programs and develop their own varieties and hybrids. However, domestic seed companies only capture between 5 and 10% of the seed market, whereas multinationals control more than 90% of the market of the main crops grown in the country, including maize, sorghum, tomato and chili, (COFECE, 2015). Although the public sector provides most of the research programs, there are very few cases of technology transfer from academic institutions to the private or productive sector. This is due to a number of reasons, such as the following: the lack of a culture of intellectual property protection, an absence of interest on the part of researchers in doing their work beyond producing a publication, lack of knowledge on the part of the private sector about the importance of research, technological development and innovation to improve competitiveness at the national and international level, which is reflected in a low level of investment in these areas and the gap between research results and productive needs. This occurs despite the fact that there are several incentives from CONACYT, SAGARPA and other Federal Government agencies, as well as state governments that provide full or partial financing for companies to undertake their own research programs or fund those of public or private academic institutes.

e. Outlook for the future

Despite Mexico's shortcomings in strengthening its programs for the genetic improvement of plants and animals, vaccine production, the genetic engineering of agricultural and livestock crops, and other strategic areas for the country's development, the human and material infrastructure required to make rapid progress in these areas is already available. This requires the implementation of a State policy to define the strategic areas of opportunity and the short-, medium- and long-term plans to boost, consolidate and achieve international competitiveness in the sectors that impact the country's agricultural development. A strategic plan is needed to increase the federal government's current investment of 0.5% of the Gross Domestic Product in science, technology and innovation to at least 1%. This plan should include strategies to facilitate and promote the technological transfer of academic institutions

Figure 3. Map showing the main soil types present in Mexico (constructed from CONABIO, 2001), complemented with the hydrographic network (CONABIO, 1998)



to companies, and encourage the participation of scientists and technologists in the creation of new technology-based companies.

III. Characteristics of Resources and Ecosystems

a. Water and the challenges for the next 50 years

Mexico's mainland aquatic systems are extremely important from an ecological point of view (**Figure 3**). The country's geographical location and relief are two factors directly affecting the availability of water resources. For the purposes of national water management, the National Water Commission (CONAGUA) has defined 731 hydrological basins. Rivers and streams constitute a 633-kilometer-long hydrological network (**Figure 3**). Regarding groundwater, the territory is divided into 653 aquifers (CONAGUA, 2014; Toledo, 2010).

Mexico annually receives approximately 1.489 billion cubic meters of water in the form of precipitation. It is estimated that 71.6% evapotranspires and returns to the atmosphere, while 22.2% runs through rivers or streams and the remaining 6.2% is infiltrated underground and replenishes aquifers. As for the country's water consumption, the agricultural sector uses 76.7%; the public water supply 14.2%; (excluding hydroelectricity), electricity 4.9%, and industry, 4.2% (CONAGUA, 2015). Per-capita renewable water available at the national level is 3,736 m^3/inhab/year (in the range of 19,078 m^3/inhab/year and 150 m^3/inhab/year). However, as a result of population growth, renewable water per capita at the national level will decrease from 3,736 m^3/inhab/year to 3,253 m^3/inhab/year by 2030 (SEMARNAT, 2012; CONAGUA, 2015). It is estimated that in some regions, only levels approaching 1,000 m^3/inhab/year will be achieved, which is a condition of scarcity according to the Falkenmark index (OECD, 2013). Regions where levels are less than 500 m^3/inhab/year, considered a condition of absolute scarcity (CONAGUA, 2015), will be at greater risk. In order to reduce the declining trend in per-capita water availability in Mexico, it is essential to implement irrigation systems and avoid open irrigation.

Moreover, water scarcity can be exacerbated by the impact of climate change. In certain parts of the North of the country, rising temperatures would reduce residual moisture in the soil during the dry months. If there is a temperature increase of between 2 and 3°C by 2050, soil humidity could be halved. This condition would have serious implications for agriculture in the region, as it would require greater water extraction, thus, more overexploitation of aquifers (Magaña-Rueda, 2006).

b. Soil

Mexico has an enormous range of soils formed over thousands of years by the interaction of the climate, the orography of volcanic origin, the type of mother rock and living beings (**Figure 3**) (SEMARNAT, 2012). Due to the importance of soils in the global food strategy, their fertility is a priority issue. Mexico lacks a comprehensive national soil strategy. However, there are programs run by the Ministry of the Environment and Natural Resources (SEMARNAT), the National Forestry Commission (CONAFOR), SAGARPA and the National Commission for Arid Zones (CONAZA), which provide economic and technical support to producers to undertake conservation works, soil restoration, land management and erosion control (SEMARNAT, 2012).

Mexico contains 26 of the 32 recognized soil groups (IUSS, 2007). Leptosols predominate in 25% of the territory and are characterized by being shallow and extremely stony (**Figure 3**), are typical of arid mountainous areas, and are unsuitable for agriculture. The next group in importance is Regosols (19%), which are very shallow and are located in arid zones (**Figure 3**). Arid zones also have Calcisols (18%), which have calcareous contents and produce pastures, grasses and shrubs, making them suitable for grazing livestock. They can be used in rain-fed agriculture with drought-tolerant crops, although they require irrigation to exploit their agricultural potential (CEDRSSA, 2015).

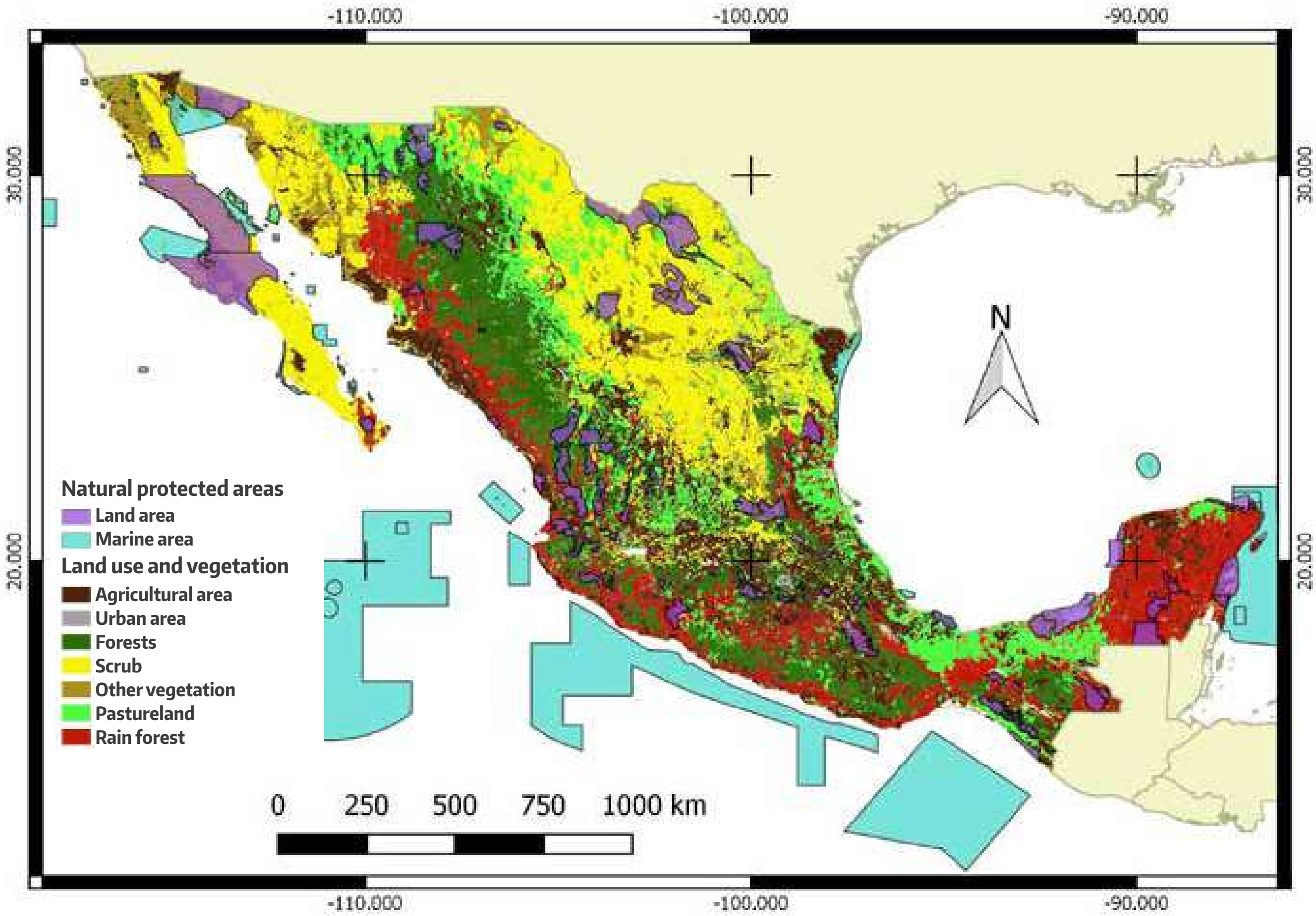
Sixty-four percent of the country's soils have been degraded, mainly due to water and wind erosion, although they also suffer from the loss of nutrients, organic matter and microscopic organisms, as well as compaction, acidification and other adverse processes, since they are used continuously (Hernández-Rodríguez et al., 2009).

c. Energy challenges

One of the most significant initiatives of the past 25 years, because of its historical, political and cultural importance, in addition to its profound economic and social consequences, is Mexico's Energy Reform. This reform seeks to consolidate public policies and strategies to strengthen the national energy sector which is undergoing a stage of great challenges, changes and transformations (Sánchez-Cano, 2014). In recent years, the infrastructure of Petróleos Mexicanos (PEMEX) and the Federal Electricity Commission (CFE) has deteriorated to such an extent that Mexico imports gas despite having it in its subsoil. It has oil, but imports its derivatives: gasoline, diesel, turbosine, Liquefied Petroleum gas (LP) and petrochemicals (SENER, 2014).

PEMEX's annual report shows that oil extraction continues to decline (it currently stands at 2.5 million barrels per day) and that PEMEX has experienced enormous difficulty in stabilizing it (Sánchez-Cano, 2014). Electricity also faces enormous challenges, since populations with over 100,000 inhabitants have electrification rates of over 99%, whereas in smaller, marginalized localities (with fewer than 2,500 inhabitants), this figure is 93.5% (Sánchez-Cano, 2014). Moreover, it has been estimated that by 2050, the energy demand will be 112% higher (OECD, 2012).

Figure 4. Map of the Mexico with information on the main types of land use and plant cover (built from INEGI, 2013). Terrestrial and Maritime Protected Natural Areas (CONANP, 2017) overlap



d. Conflicts and challenges of biodiversity

Mexico has an enormous range of ecosystems due to its location, relief, climates and evolutionary history, making it one of the world's five most biodiverse countries. This mega-diversity offers many opportunities for development and, in turn, entails enormous responsibility for its conservation and sustainable use. As in the rest of the world, the main in situ mechanism for preserving biodiversity is Protected Natural Areas (**Figure 4**). The country has a National System of Protected Areas with an area of over 17 million ha, containing 45 biosphere reserves, 66 national parks, 40 protected areas of flora and fauna, 18 sanctuaries, eight areas for protecting natural resources and five national monuments (CONANP, 2017).

i. Conflicts associated with the overexploitation of natural resources

Habitat destruction and overexploitation of flora and fauna (illicit extraction and mismanagement) are the main causes of biodiversity loss. For example, although Mexico has approximately 500 commercially important fish species (CONABIO, 2014), extraction has concentrated in a few species. Only eight commercial fisheries account for over 40% of the production volume and value of the country's total capture (INAPESCA, 2014). Moreover, it is estimated that 22.5% of the country's total fisheries are overexploited, 63.3% have reached their catch limits, and only 14.2% still have production potential (CONABIO, 2006). Overfishing is leading to the extinction of numerous marine species. An example of this problem is the case of the Vaquita porpoise (*Phocoena sinus*), in danger of extinction due to the overexploitation of totoaba (*Totoaba macdonaldi*), in demand on the international market.

Another example of overexploitation in Mexico is the case of cacti. Their multiple uses mean that they are in high demand, which has been met by the extraction of individuals and seeds from their natural habitat, affecting populations and placing many species at risk (Becerra, 2000). Mexico has 913 cactus taxa (species and varieties), of which 57% are endemic and 30% are in some category of risk (Jiménez-Sierra, 2011).

ii. Loss of genetic diversity

Plant genetic resources constitute the biological basis of food security and are key elements for the improvement of agricultural crops through conventional genetic improvement and modern biotechnology techniques. All countries rely heavily on plant genetic resources from other countries for food and sustainable agricultural development (Debouck et al., 2008). A total of 15.4% of the species consumed as food in the world originate in Mexico (CONABIO, 2006), a center of origin and diversification of maize, chili, beans, squash, tomato, avocado, cactus nopal, cacao, henequen, vanilla, tobacco and cotton (Ramírez et al., 2000). However, the country's agricultural and livestock production policies have not directly encouraged the conservation of this wealth, mainly due to the absence of incentives that promote the diversification of agricultural crops, and the difficulty of generating markets for landrace products.

e. Forest Trends

Mexico has 65.6 million ha of temperate forests and rainforests covering 30 to 35 percent of the country (CONABIO, 2014). The forest area is composed of 51.1% of forest and 49.9% of rainforest. CONAFOR estimates that approximately 21.6 million ha of rainforests have the potential for sustainable commercial production. The annual removal of wood is 56 million cubic meters, 64.3% of which corresponds to firewood, 23.2% to the production of unauthorized industrial wood and 12.5% to the production of authorized industrial wood (CONAFOR-FAO, 2009,;FAO, 2010). The main challenges for the forest sector in Mexico are: reducing deforestation – Mexico has one of the world's highest deforestation rates - and increasing the reforested area; eliminating illegal logging, exploiting the potential of timber production in native forest through sustainable management; and increasing sustained wood production through the promotion of commercial forestry plantations, such as agroforestry and silvopastoral systems (CONAFOR-FAO, 2009).

f. Potential impacts of climate change

Several signs of climate change have been observed in Mexico, such as: (i) increased desertification in the northern regions of the country; ii) extreme temperature increase; for example, in Mexico City, it has increased by approximately 4°C; (iii) intense storms, as well as long periods of heat, and (iv) forest loss and the disappearance of national glaciers located in the Pico de Orizaba, Popocatépetl and Iztaccíhuatl volcanoes.

g. Resilience to extreme events

Mexico is subject to a broad range of natural phenomena that can cause disasters. As part of the Pacific Ring of Fire, it is affected by strong seismic and volcanic activity. Two thirds of its territory have significant seismic risk and there are 14 volcanoes considered active (CENAPRED, 2001). Moreover, the country's location in an intertropical region makes it vulnerable to hurricanes, formed in both the Pacific Ocean and the Atlantic. Storms that occur during the rainy season can be intense and cause flooding and landslides. Conversely, the scarcity of rainfall affects several regions, which in turn can lead to droughts that negatively impact agriculture, livestock and the economy in general. Associated with the scarcity of rain are forest fires, which cause plant-cover loss and miscellaneous damage (CENAPRED, 2001). Although drought is the most frequent phenomenon, flooding is more likely to affect the agricultural sector when it occurs in highly productive areas (SIAP, 2016).

Vulnerability to natural disasters can depend on many variables. For example, an area with a slope greater than 25%, exposed to winds or rains (slope orientation), with little soil cover, poor infrastructure and low infiltration, is considered to be more vulnerable and less able to recover from an extreme natural event (Altieri et al., 2011). According to a recent analysis, the 20 municipalities with the least resilience in the country are located in four states: Oaxaca, Chiapas, Veracruz and Guerrero (CENAPRED, 2015).

h. Outlook for the future

The conservation and proper management of edaphic and biological biodiversity are crucial to the proper management and increase of soil fertility, and to enabling food production in a sustainable way without compromising natural resources. It is essential to implement research programs to establish in-vitro propagation systems to meet the demand for species at risk, as well as to strengthen inspection and surveillance actions in ANP. The 2025 Forest Strategic Program developed by CONAFOR must also be linked to other efforts, such as the 2030 Water Agenda, designed to consolidate the implementation of a sustainability water policy (CONAGUA, 2011).

Energy Reform encourages investment in alternative forms of energy such as wind and solar, which together with the implementation of the regulatory framework to mitigate climate change that includes the General Law of Climate Change (INECC, 2016), will support solutions to alleviate the region's high vulnerability.

There are various strategies to reduce the impact of natural disasters and create resilience. Regulating urban settlements and improving infrastructure can reduce the losses caused by disasters. Other actions include reforestation, since forests intercept winds and can have a protective effect. In addition, mature forests, which have deeper roots and anchorage, retain soil, which is important for preventing landslides. The presence of secondary vegetation also reduces the level of soil erosion, while barriers and terraces protect soil from erosion by runoff. The construction of infiltration trenches or drainage channels is key to diverting excess water, preventing floods and reducing erosion and landslides (Altieri et al., 2011). The conservation of mangroves and coral reefs helps prevent coastal disasters, while intelligent agricultural practices involving sustainable intensification reduce the pressure to expand the agricultural frontier.

IV. Technology and Innovation

a. The Role of Biotechnology

Modern biotechnology encompasses virtually all sectors of industry, particularly the food, chemical and pharmaceutical industries. Biotechnology could play a leading role in the development of agricultural and livestock activities in Mexico.

The public should realize that it offers a wide range of technological platforms with different applications and that it is not restricted to the production of transgenic or GM organisms.

i. Vegetable farming

In the case of agriculture, tissue culture for the propagation of crops such as potato, agave and flower-producing species has not achieved its full potential in Mexico. Although some successful companies propagate blue agave for the tequila industry, for example, there is still an open market for many important crops. Molecular markers and genomic strategies should be used to make crop breeding programs swifter and more effective in reducing the time and cost of producing new varieties. Molecular markers are used, albeit incipiently, in the breeding programs of public institutions, while a number of companies that produce commercial maize seeds and other crops are beginning to use these markers and double haploids in their programs. Several laboratories have DNA sequencers with the capacity to decipher and annotate plant genomes. LANGEBIO's research programs have spearheaded genome sequencing programs for beans, chilies and avocados. However, the use of genomic information for breeding programs has just begun in Mexico and has only been established by CIMMYT for the improvement of maize and wheat.

There have been efforts to research and develop bacteria that promote the growth of plants and those that improve fertilizer use, known as biofertilizers. Although this area has been used for several decades, in recent years, it has become more important due to the urgent need to reduce fertilizer and pesticide use. The study of plant microbiomes to understand which microorganism consortia have the greatest influence on productivity and resistance to biotic and abiotic factors, has an enormous future for developing more effective, crop-specific inoculants that impact productivity and reduce agrochemical use. A number of laboratories at various public institutions in Mexico are already launching research programs for the study of the microbiomes of strategic plants for Mexican agriculture such as maize and beans.

Plant engineering in Mexico has experienced a relative boom for over two decades, since the number of research groups for genetically modifying various plant species has expanded during this period. Although most groups work with model plants, there are several with the capacity to make genetic modifications in maize, tomato, potato and bean, among other crops. Two of the constraints on the development of agriculture in Mexico are: the shortcomings of the genetic improvement programs using the most modern biotechnological tools and the regulatory difficulty of approving the use of transgenics.

ii. Livestock agriculture

The greatest current impact on the livestock sector is the use of biotechnology related to animal health. Recent decades have seen the development of a broad range of therapeutic products of biotechnological origin for the treatment of diseases in the veterinary environment, as well as for use in their prevention. Included in the former are proteins, antibodies, enzymes and even various gene therapy procedures, while the latter include diagnostic kits for identifying genes or marker proteins for potential diseases or infections, as well as vaccines. In general, the animal health market in Mexico is controlled by 10 transnational companies fighting over a $1.49 billion USD market (FiercePharma, 2016). This market corresponds mainly to vaccines for the three most important livestock species in the country: poultry, cattle and swine, although there is also a major pet product market. Companies in Mexico have been established by forming partnerships with transnational companies, although several regulatory agencies have been created at the state level, such as CANIFARMA.

After the development of insulin, growth hormone was the second modern biotechnology product. In its variant for various animals (bovine somatotropin), this protein has been produced in several GM organisms and used in the livestock and aquaculture sectors. In fact, in Mexico, the use of recombinant protein was approved in the early 1990s to increase milk production in cows (Bolívar, 2004).

Probiotics and immune system stimulants have been used as an alternative to the enormous concern and rejection society has shown toward the use of antibiotics in the feeding of practically all species. Tools are available to make genetic breeding programs more efficient, such as obtaining the genome and more specifically methods for mapping resistance factors or genes with disease susceptibility or specific animal defects or characteristics.

In this later aspect, since the previous century, it has been possible to genetically modify animals to improve their characteristics. However, opposition to their introduction into the food market, and complex regulation remain a major constraint. Over the past 30 years, a dozen GM animals including pigs, cows and salmon have been developed. Given the situation at the international level, this sector has not been developed in Mexico, or at least there is no product that has been submitted to regulatory agencies. It is noteworthy that an enzyme called phytase is produced by certain companies in Mexico to be added to feed for monogastric animals, among other uses.

It is important to note the potential of modern genomic editing techniques such as TALEN and CRISPR-CAS, which impact all areas affected by biotechnology. In this case, it would be a type of genetic editing that could dispense with introducing a foreign gene into the host (McNutt, 2015; Hall, 2016).

As in other sectors, modern biotechnology in the livestock sector has given a significant boost to the existing industry. At the beginning of the 21st century, it was estimated that in the early decades, the market for biotechnology products in the sector, worth several billion dollars due to the 2,500 products available for the treatment of nearly 200 specific animal diseases, would double. However, the sector's most important potential continues to be limited by the position of a group of society that rejects the consumption of GM animals.

iii. Pests and diseases

In both Mexico and most of the countries where genetically modified plants have been authorized, *Bacillus thurigiensis* proteins have permitted the control of the most important insect pests that attack commercial crops. In environmental terms, all the reports cite the environmental advantages of specific biological insecticides, such as Cry proteins, over the broad-spectrum pesticides mentioned in *Silent Spring*, published a half century ago by Rachel Carson, outlining the toxic role of organophosphorus pesticides in health and the environment, particularly DDT. Since then, over 450 types of arthropods resistant to one or more pesticides have been detected. Fortunately for farmers and the environment, a new pest control paradigm is emerging with the use of modern biotechnology and the development of GM plants containing the genes for Cry proteins (Heckel, 2012).

After two decades of use of insecticide proteins in GM plants in Mexico (mainly cotton) and the rest of the world (cotton, maize, soy and canola), it has been possible to quantify the benefit of the thousands of liters of pesticides no longer applied as a result of the use of GM insect-resistant plants.

The elimination of the most devastating pests (Heliothis/Helicoverpa) has been observed in almost all cotton crops worldwide, including Mexico, demonstrating that Cry proteins in GM plants provide biocontrol services for agriculture, and even allow them to return to the original seeds (Lu et al., 2012; SENASICA, 2016). The economic benefits are evident, particularly in developing countries. For example, in 2015 nearly half the profits from planting GM plants were obtained by peasants in these countries (Brookes and Barfoot, 2017). In the specific case of Mexico, after 20 years of planting GM cotton, producers' earnings are estimated at $500 million USD, not counting the benefits to health and the environment by avoiding the use of toxic agrochemicals. The fact that insecticide has not been used has prevented the application of between 0.21 and 0.85 kg/ha of active pesticide ingredients. Another indirect advantage associated with pest reduction is the presence of mycotoxins in infected plants. In the case of Mexico, this advantage does not yet apply, since no other insect-resistant GM crops have been planted.

In Mexico, several key crops are economically and socially affected by extremely damaging pests, crops such as limes, attacked by a bacteria responsible for HuangLongBing (HLB) and coffee, the target of the borer beetle, *Hypothenemus hampei*. It is essential to incorporate modern biotechnology tools such as interfering RNA (RNAi) into biological control, which will provide a short cut in the fight against pests and diseases that impact agriculture.

For the Colorado beetle, a pest that affects potatoes worldwide, there is already a strategy based on this molecular tool. There have also been developments in Latin America, such as bean varieties produced by a state-owned company in Brazil that are resistant to the golden virus, transmitted by the white mosquito. In Mexico, the main challenge remains the reduction of the amount of pesticides used in agriculture, particularly in corn for controlling worm-eaters (*Spodoptera frugiperda*) for which 3,000 t of active ingredient are applied annually. This is followed by lepidoptera, such as the black cutworm (*Agrotis ipsilon*) and the corn earworm (*Helicoverpa zea*), controlled by one-to-three insecticide applications every season (Blanco et al., 2014).

b. Prospects for novel agricultural products

Technologies developed in Mexico using plants' genetic modification include the production of drought-tolerant plants by a group from CINVESTAV in Mexico City, as well as those requiring fewer fertilizers and herbicides for their optimal productivity, developed by CINVESTAV researchers in Irapuato.

The strategy for producing plants with higher drought tolerance is based on increasing the content of trehalose, a disaccharide that has been associated with water-loss tolerance in many biological systems. Increasing the concentration in plants was unsuccessful due to the overexpression of the genes that encode the enzymes responsible for its synthesis. Accordingly, Beatriz Xoconostle's group at CINVESTAV in Mexico City used a strategy to reduce the expression of genes that destroy trehalose, which raised the level of trehalose in maize plants, thereby increasing their drought tolerance.

In order to create crops requiring less fertilizer, a novel strategy was used based on solving the main problem of the use of phosphates as a fertilizer to boost crop growth. The main problem is that phosphates react quickly with the cations present in soil particles and are strongly fixed by adsorption and unavailable for plant roots to absorb them. Phosphates are the only chemical form of phosphorus plants are able to use. To solve the phosphate problem, the research group run by Dr. Luis Herrera at CINVESTAV, Irapuato, used phosphites rather than phosphates, since the former do not react with the cations in soil particles and are therefore far more readily absorbed by roots and potentially a much more suitable fertilizer. The problem is that plants are unable to metabolize phosphite, thus they cannot feed on that source of phosphorus. In order to be able to use it as fertilizer, plants were genetically modified so that the phosphite absorbed by the root was converted to phosphate, in other words, a non-metabolizable molecule was converted into a nutrient. When implemented, this system can selectively fertilize the GM crop, which can save up to over 50% of fertilizer as well as decreasing the use of weed killer- Since weeds are unable to use phosphites as a source of phosphorus, they will not be able to grow rapidly and therefore will not affect crop productivity. These two examples are proof of the potential of research in molecular biology and plant biotechnology in Mexico.

c. Opportunities and obstacles to new management technologies

For reasons of cost and in order to reduce the environmental and ecological damage caused by agriculture, it is essential to reduce water and agrochemical consumption. Improved irrigation systems coupled with the use of improved varieties, including genetically modified ones, provide a major opportunity to increase agricultural productivity by reducing the ecological impact. However, achieving this requires establishing long-term public policies through funds to promote the use of efficient irrigation systems and the use of improved seed for all crops. For example, for a variety of reasons, the use of genetically modified crops has been on hold for over 20 years, despite the fact that a biosafety law on genetically modified organisms was passed over 10 years ago.

d. Development of aquaculture/ marine resources

Among the countries that engage in fishing activity, Mexico moved up from 30th place in contribution to total catch during the 1950-1980 period to 17th in the past 20 years, and currently produces about 1.5% of the world's total volume. Conversely, in relation to aquaculture, there were about 151 thousand t of products grown in marine, freshwater and brackish waters, meaning that Mexico ranked 25th worldwide (CONAPESCA, 2010). However, it is important to note that there are regional productivity differences. The Pacific coast states contribute the largest volume of fishery and aquaculture products, with an average percentage of 80%, followed by the Gulf and Caribbean shore with 18% and 2.0% of Inland Waters, respectively (DOF, 2014).

In 2012, fishing and aquaculture accounted for approximately 0.18% of Mexico's GDP. These activities are crucial to the production of foods with high protein value for human consumption and their contribution to microeconomics. In 2012, national fishery and aquaculture production stood at 1.68 million t, 85% of which corresponded to fishing and 15% to aquaculture. Nationwide, six species account for 69% of the total value of fish production: shrimp, tilapia, tuna, octopus, sardine and trout (DOF, 2014).

Three species account for 79.7% of the total volume of aquaculture: bream, shrimp and oyster. A total of 9,230 units of aquaculture production with an area of 115.910 ha have been recorded, with 75% being cultivated with shrimp alone (CDRSSA, 2015b). Moreover, in the past ten years, aquaculture in Mexico has experienced an average growth rate of 3.4% and is identified as a viable alternative for reducing the pressure on wild fish resources. Nonetheless, aquaculture faces enormous challenges regarding genetic improvement, health, quality and safety, and the elaboration and production of balanced diets that must be met if it is to be developed in a sustained manner, so as not to depend on the importation of inputs (DOF, 2014) or the overexploitation of this activity.

V. Enhancing the efficiency of food systems

a. Outlook for increased technology-based agricultural production

In 2008, the European Union Joint Research Center (JRC) undertook a study on worldwide biotechnological development, in both the public and private sectors. It predicted that by 2015, there would be 91 new characters conferred on plants already on the market. These characters would provide protection from pests and diseases, resistance to climate factors and additional nutritional properties, such as the elimination of toxic characters, worldwide. By 2014, there were only 16 new characters on the market, mainly agronomic and developed by the private sector.

What has become of all the expectations related to improvements in nutritional quality, food safety and crop safety?

A study in 2012 of technology developers in this sector concludes that, on average, it takes US $136 million and approximately 13 years bring a product to the field, despite technological improvements and the efficiency of manufacturing processes. Nonetheless, the cost and time involved in the regulatory process has increased by 50% over the past decade, making marketing difficult, although many of the developments were achieved in the public sector and therefore do not involve royalty payments to the producer.

The modification of agricultural characteristics is expected to have an indirect impact on factors such as water availability and temperature. Whereas precision agriculture favors the extremely controlled use of water and nutrients in crops, it is likely that changes in the physiological properties of seeds will have the greatest impact on productivity in the short and medium term. Thus, reports have been written on the design of more efficient plants by modulating the expression of certain genes. In the case of maize, for example, regulation of the expression of the *Plastochron1* gene coding for a cytochrome c increases biomass and seed yield, lengthening the duration of cell division (Sun et al., 2017). The same can happen through modifications that achieve more efficient photosynthesis, or greater carbon use.

b. Infrastructure needs

Mexico currently has over 3,000 agricultural warehouses, 1,133 animal slaughterhouses, 89 wholesale food outlets, 65 fishing ports, 26,727 km of railway, 389,345 km of road network and 3,093 dams for agricultural irrigation (SIAP, 2016). Nevertheless, it is essential to invest in infrastructure to connect trunk distribution hubs and streamline port operations and capacity. Also, at the local level, there is a need to consolidate product collection networks, in order to reduce the intermediaries and the producers who receive a direct income from the marketing process.

Greater investment is also required to reactivate the railroad as the most economic means of transporting agricultural products. Last, it is necessary to invest in infrastructure to make efficient use of water in the agricultural sector and to have drip, rainwater and mist-collection irrigation systems.

c. Food use and waste minimization strategies

The food industry comprises 22% of the total manufacturing industry nationwide (COMECYT-FUMEC, 2009). The states with the largest number of economic units of processed foods are: the State of Mexico, Puebla, Oaxaca, Mexico City and Veracruz (Terán-Durazo, 2015). Most food companies concentrate on the production of bakery and tortilla products (31% and 22%), respectively followed by industries specializing in the slaughtering, packaging and processing of livestock and poultry (22%) and then dairy farms (12.6%).

It is estimated that 37.26% of food in Mexico is wasted, equivalent to 10.4 million t per year, creating a loss of over 100 billion pesos. Some of the causes of waste can be found in the value chain, lack of certification, lack of quality standards, inefficient management, bad practices, inadequate packaging systems, transportation, distribution and storage, and lack of training. Consumers are also responsible for waste, due to excessive purchases or improper handling of merchandise (FAO, 2015). To address this problem, the National Crusade against Hunger Council 2016 presented several strategies to reduce food losses: the creation of the Technical Group on Food Losses, the implementation of the "Creation of Productive Chains in the Coasts of Mexico" project, support for research on practical, technical solutions for food waste, and the distribution of recovered food in the poorest areas of the country, with the support of the Mexican Association of Food Banks, comprising 60 banks in 29 states (SEDESOL, 2016). The implementation of these strategies and their effectiveness should be carefully evaluated.

d. Conflicts between food production and energy production

The need to achieve food self-sufficiency by increasing food production and the search for alternative sources of renewable energy from agricultural raw materials is a global conflict (Ajanovic, 2011; Graham-Rowe, 2011). However, the conflict is particularly critical in a country such as Mexico, where maize constitutes the basis of the diet, yet at the same time, together with sugar cane, is the best choice for the production of first-generation biofuels. This is compounded by the fact that the country's economic growth - sustained by oil exports for decades - has been heavily affected by the reduction of production capacity, due to the exhaustion of the most important wells, and the fall in international oil barrel prices.

Despite the need to gradually replace fossil energy with renewable energy, in an attempt to strike a balance between the use of soil for food supply and the production of energy inputs, in February 2008, Congress issued a Law on the Promotion and Development of Bioenergetics, which sought to protect food sovereignty and security and prevent the risk of loss from a government perspective. However, it is a controversial instrument, since it paradoxically inhibits the promotion of bioenergetics and has limited the adoption of sustainable energy-supply models in Mexico. This situation is not only compounded by low oil prices in the international market, but also by the development of recovery techniques through fracking that have given the U.S. energy independence, although from the point of view of sustainability, this technology constitutes a setback.

In principle, the law was intended to promote market development, the promotion of participation schemes and free competition in this sector. The Intersecretarial Commission for the Development of Bioenergy was created, formed by the Secretariat of Energy (SE), SAGARPA and SEMARNAT. The first two were tasked with the issuance of Official Mexican Standards (NOM) and permits, and the third with dealing with the environmental liabilities caused by the production, transportation and commercialization of bioenergetics. Last, the law includes procedures, infractions and sanctions related to the sector (Ampudia, 2008; Quadri, 2012).

All this has spawned a complicated system of requirements, with high transaction costs for the producers of inputs for energy purposes (maize, cane, stubble, oilseed, etc.), discouraging development and technological innovation. It is important to recall the current ban on high-yielding GM corn, without which productivity is at best maintained by native varieties. SAGARPA only issues a permit to produce biofuels from corn when there are surplus inventories of domestic grain production to satisfy national consumption. For agricultural crops other than maize, notice of planting must be submitted to SAGARPA. Producers must also state that they will be cultivated exclusively on farmland and that forests will not be converted to agricultural land. Moreover, in Mexico there is limited availability of land for cultivation (approximately 33%).

It has been pointed out that this law gave rise to an unconstitutional rule, since it affects the right of ownership and the freedom of industry of producers of agricultural inputs for bioenergetics, as well as of those who market and consume them. In short, the high transaction costs generated by the NOM regime and previous permits, coupled with the legal impossibility of using GM organisms to increase productivity - even if only for industrial use - have prevented both the food and energy sectors from being properly developed in the country. Indirectly, projects to produce biofuels made only from jatropha, oil palm and sorghum as raw materials have been encouraged. A clear policy and programs to promote alternative strategies are urgently needed to produce biofuels with microalgae or other photosynthetic organisms that would not compete for arable land, such as maize or sugar cane.

VI. Public Health Considerations

a. Foodborne diseases

There is a broad spectrum of public health diseases, gastroenteritis and diarrhea being the most frequent symptoms associated with their condition and attributable to various microbial pathogens including bacteria, viruses and various parasites. Unofficial figures suggest that there are 5 million cases annually. The susceptibility, severity and lethality of these diseases depends on several factors, such as the person's immune status, nutritional condition, age and certain other factors specific to each ailment. As one might expect, the most susceptible populations are children under the age of five, expectant mothers, the elderly, and last those who for some reason are immunocompromised. Additional complications can arise when a person suffers from other diseases, particularly those associated with metabolic syndrome and diabetes.

According to the Center for Epidemiological Surveillance and Disease Control, which belongs to the Secretariat of Health, in 2011, there were 5'345,571 cases of intestinal infectious diseases, whereas by week 51 of 2016, the number had decreased to 4'822,218 (Boletín Epidemiológico 2016). Between 2011 and 2015, the weekly average of new cases of intestinal disorders was 62,311. Statistics include diseases such as cholera, typhoid, paratyphoid, salmonellosis, shigellosis, ill-defined infections, intestinal amebiasis, amebic liver abscesses, those caused by protozoa, giardiasis and helminthiasis. Diarrhea is the most common condition associated with food poisoning (*salmonellosis*, *Escherichia coli*, *staphylococci*, etc.), although there are more dangerous conditions such as listeriosis, botulism, toxoplasmosis and hepatitis A, for which age is the most important component of morbidity and mortality, since it increases in a directly proportional manner to this factor.

The states with the highest incidence of gastrointestinal diseases, in order of importance, are: Mexico City, Jalisco, followed by Veracruz, Nuevo León and Chiapas. Conversely, the states least affected by these digestive disorders are: Campeche, Tlaxcala and Quintana Roo, although these are total data that do not take population size into account.

b. Overweight and obesity

Like most of the world's countries, Mexico is experiencing a severe crisis of overweight and obesity, so much so that in 2016 the Secretariat of Health issued an epidemiological emergency due to diabetes and obesity given the magnitude and importance of the problem. The figures are as alarming as in the rest of the world. According to data from the National Health and Nutrition Survey (ENSANUT, 2012), 71.2% of the adult population in our country (about 55,372,611 people) were overweight or obese, while 9.2% (7'154,888 people) had diabetes. Specifically, 10 million Mexicans have been diagnosed with diabetes, meaning that Mexico ranks 9th worldwide. However, the figure may be higher, since six of 10 diabetics had never had their blood sugar measured until they saw a doctor as the result of a related symptom. It is one of the leading causes of death in the country, with a logarithmic increase in the mortality rate, from 2.0 to 70.9 deaths per 100,000 inhabitants between 1930 and 2008. It has been estimated by the Secretariat of Health that 98,000 Mexicans a year currently die because of diabetes, due to its association with other diseases such as hypertension, neuropathy, nephropathy and atherosclerosis, with diabetes being the main current cause of blindness, since two of every five persons with diabetes end up suffering from it. The costs to the Health System is extremely high since 14% of diabetics require dialysis, 30% of those who develop diabetic foot end up with an amputation and 10% develop neuropathies.

It is a well-known fact that 90% of diabetes cases are associated with poor eating habits and physical inactivity. In Mexico, the situation is compounded by Mexicans' propensity to consume refined sugar, mainly through soft drinks (Hert et al., 2014). Mexico ranks first in annual soft-drink consumption, with 163 liters (1) per capita, 40% above the U.S., where per-capita consumption is 118 liters. Consumption tripled between 1999 and 2006. It is estimated that seven of 10 children in rural communities accompany the first meal of the day with a soft drink (Ávila-Nava et al., 2017).

Given that a quarter of Mexican's caloric intake is derived from soft drinks, strategies and campaigns aimed at changing consumer habits have focused primarily on sugary drinks, particularly among children. This constitutes a serious social and economic conflict, since this public health problem is associated with a crop that supports more than two million Mexicans who earn their livelihood from sugar-cane harvesting and processing. Indeed, Mexico is self-sufficient in cane sugar, with an average production of 52 ml t/year (2004-2014), yet has encountered serious trade problems with the U.S. in exporting its surplus. This year (2017), even before the review of the North American Free Trade Agreement (NAFTA), the refined sugar export quota to the U.S. has been substantially reduced, meaning that Mexico can only export unrefined sugar. At the same time, soft drink bottling is one of the most powerful industries within the country's food and economic sector (Clark et al., 2012).

c. Expected changes in the current consumption pattern (and implications for food imports)

Toward understanding and encouraging changes of attitude toward consumption. Emergency of personalized nutrition

As of January 1, 2014 in Mexico it was decided to levy a $1/l (Mexican peso per liter) tax on sweetened beverages. In an article published in the British Medical Journal, a year after this measure had been applied, researchers from the National Institute of Public Health, in collaboration with researchers from the University of North Carolina, concluded that bottled soft-drink purchases had fallen by 6% over the same period in 2014 (Colchero et al., 2016), particularly among low-income families. This groundbreaking study in quantifying the effect of this type of policy concludes that, although the change is moderate, it is essential to continue implementing and assessing the program, particularly to detect how consumers have adjusted to the measure. The policy should be accompanied by an intense campaign to prevent access to sugary drinks in schools and introduce drinking fountains. However, there are as yet no data on the compliance with and impact of these measures.

The "Hispanic Paradox," a term coined by Kyriakos Markides to describe a 30-year-old epidemiological phenomenon among Hispanics in the U.S., refers to the fact that Hispanics have greater longevity, despite their unfavorable socioeconomic status and difficulties in accessing the health system (Anonymous, 2015). The editorial refers to a report by the U.S. Centers for Disease Control (CDC), which confirms the differences between Hispanics and the White population. Hispanics showed a 24% lower risk of suffering any of the 15 leading causes of death among U.S.-born Whites, primarily cancer and heart disease. This does not spare the population from diabetes, which, together with liver diseases and death from homicide, are substantially higher among Latinos than Whites, as is the problem of obesity. The article concludes by pointing to the fact that health authorities cannot ignore the health of Hispanics, particularly considering the current trend toward personalized medicine and the risk factors associated with each population. In this regard, specific studies by the National Institute of Genomic Medicine in Mexico have unveiled genetic risk factors for diabetes associated with Mexicans. They refer to specific mutations not seen in European or Asian population, or even in the northern regions of the country, but among Cora and Maya Indians, and to a lesser extent, among the Zapotec and Otomí.

An analysis of the correlation between the weight differential between Mexican and U.S. populations and their evolution since NAFTA raises the question of whether, in public health terms, this is a good agreement for Mexico in terms of health. The percentage of obese women in 1988 was 10% in Mexico, compared to 25% in the U.S. By 2006, these figures had risen to 32 and 35% (Young & Hopkins, 2014), in other words, the health advantage that the Mexicans' diet had conferred before NAFTA had been lost. Despite constituting 11% of the population in the U.S., the Hispanic population accounts for 33% of the consumption of beans which, together with corn, constitutes the base of the Mexican diet. In per-capita consumption, Hispanics consume 4 to 5 times more beans than the White population. Studies are still required to determine the causes that contribute to this correlation.

In the case of corn, tortilla consumption in Mexico decreased by 30 kg per capita annually in the last decade, triggered by the elimination of the government subsidy on corn prices, according to information from industrialists in this field. In 1997, when it was decided to eliminate the tortilla subsidy, average annual tortilla consumption was 120 kg per capita. A decade later, every Mexican eats an average of 90 kg of tortilla a year, in other words, 25% less. One of the main instruments used by Mexican health authorities to deal with the problem of diabetes and obesity is the recovery of the traditional diet, and the cereals, vegetables, fruits and dishes it comprises. The fact that Mexican cuisine has recently been recognized by UNESCO as intangible world heritage, coupled with widespread evidence of the health benefits of its ingredients, lends credibility and support to any health campaign for Mexicans.

VII. Political considerations

a. Public programs and subsidies in the Mexican agricultural sector (Distortions created by subsidies and other outmoded agricultural policies)

In 1940, the State adopted a key role in regulating economic, political and social relations for the countryside, with particular emphasis on welfare processes. Agricultural policy in the 1970s and 1980s was based on increasing direct government interventions through price guarantees and subsidies for the acquisition of credits, inputs and food consumption focusing mainly on grain and oilseed producers. Support was provided for storage, distribution and processing, as well as corn tortilla price subsidies. Commercial protection through the application of import licenses resulted in poor performance by the agricultural sector, which in turn led to rentierism, unemployment and inefficient production (Yúñez, 2010). These policies created distortions and discretionary support, limiting access to certain sectors of the population.

Following the constitutional reform of 1992, Article 27 was amended and a new Agrarian Law enacted with a two-fold aim: i) delimit the expansion of the agricultural frontier due to land distribution and the growth of smallholdings, and ii) promote the market of lands belonging to the ejido due to the stagnation of production (Taylor et al., 2007). To this end, new regulatory schemes were established with the aim of reducing the public and administrative expenditure of the State, which reoriented federal policies in this area. Due to the prevalence of smallholdings, the heterogeneity of conditions in productive agricultural units and differences in the development of the states, the sector suffered from a lack of market access, technological backwardness, low productivity, low incomes and migration from the countryside to the city (FAO-SAGARPA, 2012). Consequently, agrarian development policies have diversified over the years to meet the needs of productive units by channeling various supports and subsidies into them (SAGARPA, 2017, FIRA, 2015).

In the 1990s, programs were promoted to combat rural poverty and the sustainable use of natural resources and public policies were designed to facilitate the transition of the sector to the free market context, in line with the passage of NAFTA. The Support and Services for Agricultural Marketing Agency (ASERCA) and its various programs have operated since 1991 through subsidies to producers and buyers, mainly for grains and oilseeds. The Direct Support for the Countryside Program (PROCAMPO) was established in 1994 as a system to lend certainty to low-income producers and eliminate the distortions caused by guaranteed support. Its main objective was the reorganization of activities and crop conversion to shift to more competitive varieties and reduce dependence on basic crops. Its inclusive aim made the instrument less accurate. Due to the lack of clarity regarding its objectives, the program was used with interpretations in the transfer of resources to support the current income of rural producers, or to strengthen productive aspects of agricultural units. Public subsidies encouraged transfers that offset the effects of international competition on domestic producers, most of which benefited ejido owners of rain-fed farmland. Unfortunately, the atomization of funds in smallholdings and the low performance of the agricultural productive units that received support continued.

Lack of precision, targeting problems, irrelevant support and absence of coordination with other public policies in the sector strongly limited results (FAO-SAGARPA, 2015a). A similar thing happened with other programs due to their modular application. Their implementation created inequalities among beneficiary producers and negative effects on non-beneficiaries, further polarizing the countryside (Taylor et al., 2007). The State's commitment to streamlining the use of resources through increases in investment and bank loans has not been fully achieved. Evaluations of guarantee programs indicate that credit subjects have mainly been producers from higher income strata, since they have less difficulty providing the guarantee requirements requested by the financing institutions (FAO-SAGARPA, 2015b). Productive stratification persists with very poor sectors that prefer to migrate from the countryside and continue the process of reorientating the national agricultural supply toward the production of more competitive crops to leverage global market trends. Family farmers who used the programs concurrently achieved better performance (FAO-SAGARPA, PROCAMPO Component and Guarantees Component).

Since 2001, a new legal framework has encouraged the concurrence of programs to improve their effectiveness and interrelation. The main policy instrument in force is the Concurrent Special Program for Sustainable Rural Development (PEC, 2012), which brings together public policies on rural development. Structured in nine aspects, under a scheme of intersecretarial co-responsibility, it promotes 10 regional multisectoral strategic projects aligned with the National Development Program and leverages the National System of Support to Programs Inherent to the Promotion of Sustainable Rural Development Policy, with productive, competitive and social approaches.

b. Promotion of nutrition-sensitive agriculture to provide healthy, sustainable diets, linked to resource use and food prices

Mexico is classified as having a moderate level of food insecurity, with regard to access to food. Nationwide, 23.3% of the population has deficits in access to food, rising to 32% in rural areas. The National Crusade against Hunger (2014) recognizes that food deprivation is the result of a complex, multidimensional socioeconomic environment that requires a holistic approach and multiple public policy instruments for food, health, education, housing, services and income.

The Integral Rural Development Program (PIDER) was created in 2014 to address the problems of food insecurity experienced by a high percentage of the country's rural population, based on the regrouping of previous programs (CONEVAL, 2015). Its purpose is "to contribute to eradicating food shortages in rural areas by producing food with a sustainable approach for the population in extreme poverty in marginalized and peri-urban rural areas, so that this population can produce food with a sustainable approach". In this context, SAGARPA and the Secretariat of Social Development (SEDESOL) provide support to encourage family farming, productive projects and welfare services. Efforts have also been made to promote the component of the Special Program for Food Security (PESA), an FAO-SAGARPA collaboration aimed at achieving the food and nutrition security of families from rural areas with high and very high marginalization. In 2016, 26,036 productive projects benefited 207,762 families from 8,594 rural localities in 923 municipalities, with the support of 332 Rural Development Agencies (SARD) and 12 Multidisciplinary Technical Teams (PESA-85, SAGARPA, 2016a). The results obtained will have to be evaluated to determine the effectiveness of these programs and decide whether they should be continued and extended in future administrations.

c. Policies that encourage technological innovation

Expenditure on agricultural research and development accounts for a mere 0.016% of total GDP. Federal spending on agriculture corresponds to just 10.2% of the total budget allocated to the Special Concurrent Program (PEC) for research, development and technology transfer (CEDRSSA, 2017). The most recent CONEVAL evaluation indicates a low effect of research and technological development activities on productivity and their low use in productive processes. The limited application of innovations and knowledge is compounded by the fact that there is no effective link with producers' demands and needs. Public policies in this area are usually fragmented and the objectives of existing programs are too broad and inaccurate, hampering the effectiveness of public investment for research and technological development in the sector (CONEVAL, 2015). Nevertheless, PIDER components include the Integral Development of Value Chains to promote productive aspects and technical assistance and training, and Outreach and Productive Innovation for outreach activities in states, linkage with national and foreign institutions, training and agricultural education outreach.

CONACYT allocates resources for basic and applied research through institutional funds and the CONACYT-SAGARPA Sectoral Fund to maintain the Research, Innovation and Agricultural Technological Development component, aimed at solving problems in the production, industrialization or commercialization of products, integrating biodiversity and modernizing the production of agricultural crops with machinery and equipment (SAGARPA, 2016a). There are other programs designed to enhance the competitiveness and coordination of agricultural production chains through the improvement of technical and research capacities, as well as the maximal use of binding entities, such as the National Research and Technological Transfer System for Rural Development (SNITT), the National System of Training and Integral Rural Technical Assistance (SNCATRI), the CONACYT Thematic Networks and the PRODUCE foundations, which foster links between research institutions and user producers. However, the lack of clarity of these programs, the indefinition of strategic priorities and the opacity of the mechanisms for granting support limit their effectiveness.

On the basis of sectoral diagnoses (CONEVAL, 2017), it has been observed that stagnation depends on the poor genetic quality of seeds and low investment in innovation to improve value chains. The Sustainable Modernization of Traditional Agriculture (MasAgro) Program is a rural research and development project sponsored by SAGARPA and CIMMYT and designed to promote the sustainable intensification of maize and wheat production in Mexico. MasAgro develops research and capacities designed to increase the profitability and stability of maize and wheat yields. The Program also seeks to increase farmers' incomes and the sustainability of their production systems through collaborative research schemes, the development and dissemination of adapted seed varieties, and sustainable agronomic technologies and practices.

Technological options include the development of productive strategies and innovations using modern biotechnology. These latter applications are subject to regulation through the LBOGM, which establishes that resources will be allocated through the CIBIOGEM FUND to promote research, development and innovation projects in biotechnology, designed to solve the country's specific productive needs and directly benefit national producers (LBOGM, 2005).

d. Policies that strengthen human resources

In the 1990s, private technical assistance was promoted, with costs being absorbed by the government and producers. This third-party model requires the development of professional services with trained personnel and the ability to encourage producers' participation. In 2016, a list was compiled of 3,836 outreach workers, who benefited 150,000 producers from 31 states in the E1, E2 and E3 strata (SAGARPA, 2016a). Through Objective 2, the PEC "...encourages the training of high level human capital, associated with the development needs of the rural sector," for which there is an Education and Research Program for capacity building in education and training professionals in agricultural work. Efforts have also been made to consolidate women's strategic participation in the agricultural sector through social inclusion and gender equity programs. Between 2011 and 2015, women's participation in productive work was 19.7% while their access to land ownership has gradually increased. Programs such as PROMETE (Fund for Supporting the Productivity of Entrepreneurial Women) are designed to promote women's participation in productive projects (SAGARPA, 2016b). Other programs such as PROSPERA education, PROSPERA social inclusion, agricultural workers and capacity building in education are also oriented toward human resource training.

e. Policies that redesign agricultural ecology (land use, bioeconomics, etc.)

The PESA component lends continuity to programs for the promotion of agricultural ecology projects. Beneficiaries receive support packages for family gardens and farms, and training and technical services are provided directly, in an attempt to achieve an agroecological approach. Resources focus on the development of family orchards and backyard agricultural projects, which benefit women and the elderly living under marginalized conditions. The Family, Peri-urban and Backyard Agriculture component is used to encourage food production in 57 urban and peri-urban areas in 20 states, and horticultural, poultry and fruit packs have been delivered for food production, mainly for self-consumption.

The Integral Value Chain Development component supports projects for products such as honey, coffee, lime, prickly pear, walnut, mango, papaya, bananas, maize, beans, vegetables, sheep, cattle (beef and milk), tilapia and shrimp, among others, benefiting people in extremely poor rural areas with high or very high marginalization.

Three components are available for sustainable regional development and wildlife protection. These programs provide economic support to people residing in localities located in protected natural areas, priority regions and areas of influence, to undertake projects, technical studies and training courses designed to conserve ecosystems and their biodiversity, or produce wildlife management units. The approach is designed to benefit 20 authorized species and conserve the habitats of other endangered species (CEDRSSA, 2017).

f. Policies to promote the consumption of healthy foods

Mexico has a long history of implementing programs and policies aimed at improving the nutrition of vulnerable groups (Baquera et al., 2001). In this regard, the Secretariat of Health has launched major campaigns on nutrition and healthy eating habits. The main national policies are oriented toward food production and consumption, with subsidy programs for food products in the basic basket, tortillas and milk. Direct interventions are promoted for complementary micronutrient supplementation and nutrition education for vulnerable groups. Human development and food support programs, social milk supply (LICONSA) and school breakfasts are implemented through the System for Integral Family Development (DIF).

The National Crusade against Hunger, involving the coordination of 70 federal programs in 19 units for the allocation of resources with national coverage, has the following objectives: reduce the hunger of people in extreme multidimensional poverty, through adequate food and nutrition; eliminate acute malnutrition and improve child weight and height indicators; increase the food production and income of peasants and small farmers; minimize postharvest and food losses during storage, transportation, distribution and marketing; and promote community participation to eradicate hunger. Moreover, special attention is paid to the safety of the food consumed by the actions of the Federal Commission for Protection from Health Risks (COFEPRIS, SSA) and the National Food Safety and Quality Service (SENASICA, SAGARPA).

g. The country's comparative advantages in agriculture

Mexico's geographical position, diversity of climates and large territory provide a great variety of crops and agricultural, fishing and livestock species. As a result of its infrastructure and human resources, the country ranks 12th in world food production, 13th in agricultural crops and 11th in livestock production (SAGARPA, 2016b). Although there are constraints on agricultural production units, the productive sector as a whole is highly competitive with a diversified portfolio of high-quality fresh food and produce.

h. International trade issues

Mexico currently has a positive agri-food trade surplus and a growing annual agri-food trade. It is a leader in international agricultural and agroindustrial markets with good potential for growth, mainly in beer, avocado, tomato, tequila, beef, vegetables and fruit. The agri-food exports sector is dynamic, with 11 free trade agreements with 45 countries, constituting a potential market of approximately 1.462 million people, and constantly seeks new market niches to improve sales of agricultural, livestock and fishery products. According to international standards, the state promotes health policies with the purpose of increasing the supply and competitiveness of Mexican agricultural products and reducing access barriers to national and international markets.

i. Market challenges

Population growth will be the main driver of global demand for agricultural commodities over the next few years. With a population projection of 8.1 billion by 2025, food demand must be met by improving efficiency, expanding production options that create only small increases in the production base (OECD-FAO) and streamlining the use of the sowing surface of crops and cattle herds. This will test the technological alternatives available to the agricultural sector to achieve sustainability and market supply goals.

According to FAO indicators, agricultural commodity price projections are declining, with a tendency to stabilize in the medium term. It would be useful to have agricultural technologies that add value to products. In this respect, challenges continue to focus on increasing the productivity of the sector, maintaining the competitiveness and quality of the food exported, while at the same time, combining social and productive objectives for the sustainable use of natural resources and the conservation of biological diversity.

VIII. Abstract

a. Potential national agricultural scenarios for agricultural production in the next fifty years

Mexico faces enormous challenges to its food and nutrition security, which will only be able to be resolved through the coordinated action of various sectors that have an impact on the production problem. On the one hand, there is a need to implement strategies for adaptation to and mitigation of climate change, and to include programs for the conservation and sustainable use of biodiversity and genetic resources for agriculture and food. There is also an urgent need to boost effective investment for the development of the countryside through partnerships between the public and private sectors and academia, in order to generate innovations that solve all the productive problems of the various strata involved in food production. It is also necessary to promote educational programs and technical and scientific training to attract young people to the countryside, and for the activities associated with it to be a genuine source of decent work. All this is associated with trans-administration agricultural policies that allow continuity and follow-up for effective programs and adapt those that require improvements. This takes place in a regulatory context that encourages innovation and provides security for investment and the strengthening of agricultural practices that ensure food independence in a sustainable manner, while supplying a competitive market at fair prices for producers that are affordable for the entire population.

b. Priority actions to achieve and preserve agricultural sustainability

Mexico has vast natural resources, diversified agricultural capacity, operational institutional infrastructure and competition in technological development. There are state policies focused on addressing the main problems of agriculture, nutrition and the environment, usually implemented in a modular way in an incipient transversal scheme. It would be useful to publicize national strategies for the concurrence of public policies and coordinate their implementation to provide greater clarity and regulatory certainty, promote synergies and joint institutional actions and leverage the nation's advantages in order to achieve the food security and sustainability objectives demanded by Mexican society.

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Acknowledgments

The authors would like to thank **Gerardo Sotomayor Serrano** for his help with the editing and copy-editing.