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The Agro-Industrial Sugarcane System in Mexico: Current Status, Challenges and Opportunities

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Abstract

Sugarcane cultivation in Mexico occurs under a wide range of socioeconomic, environmental and agricultural conditions, with the last three harvests (2010/2011, 2011/2012 and 2012/2013) providing yields ranging from 36-125 t ha^{-1} (variation > 347%), with an average yield of 70.2 t ha^{-1}, which is below the world average of 80 t ha^{-1}. The total area allocated to sugarcane production in Mexico is close to 800 thousand hectares, and could rise to nearly 5 million hectares given adequate conditions for its cultivation. This activity generates approximately 1 million direct jobs, 2.2 million indirect jobs, and more than 2.5 billion dollars (0.4% of GDP) per year. Climate change and the rapid market penetration of high fructose corn syrup are among the greatest threats to this agribusiness, including severe disintegration of production processes in the field, industry, commerce, and consumption of cane sugar. Technology lags, low investment, high processing costs and shortcomings in production sales are issues the industry must address by leveraging their resources and coordinating processing links to be more efficient and competitive. Political influence has imposed a suboptimal policy framework to achieve the projected potential. To overcome current lags in the field and refineries within the country, significant innovations across the value-chain are underway, including a robust breeding program, digitalization of sugarcane fields and novel investments in research and development. The sugarcane value-chain has great potential for Mexico, and exploiting this potential is possible if technological, organizational and commercial management innovations currently in progress in fields and factories are applied.

Keywords: *Saccharum*, mexican agro-industry, sugar yield, innovation

1. Introduction

Sugarcane (*Saccharum* spp.) is the most productive crop in the world due to its higher efficiency in photosynthetic capacity, and its ability to store sucrose in its stem. Sugarcane contributes 75% of the total sugar produced in the world with the remaining 25% produced from sugar-beets (*Beta vulgaris* L.). Its high biomass production and ease of growth make sugarcane one of the most interesting agricultural commodities globally, useful not only in food and feed, but also in the generation of inputs for bioenergy and chemical industries. Its cultivation covers an area over 25.4 million hectares in more than 130 countries and territories, with production of more than 1800 million tons, thus establishing sugarcane as the crop having the most acreage in the world (FAOSTAT, 2013). Average global production is approximately 80 t ha^{-1} (Waclawovsky, Sato, Lembke, Moore, & Souza, 2010), although theoretical yields are estimated near 470 t ha^{-1} dry matter or 805 t ha^{-1} of fresh cane per year (Yadav, Jain, & Rai, 2010; Dal-Bianco et al., 2012), which supports the hypothesis that increased future yields are possible. Diversification of products (transition from simple sugarcane mills to sugarcane biorefineries) utilizing the entire crop for a variety of environmentally friendly outcomes apart from sucrose, is the key factor in today's highly integrated sugar milling operations, generating a wide range of other products such as energy, human food, animal feed, manures, biofuels, ethyl alcohol and its derivatives. In fact, it is possible to derive more than 10 000 new products from sucrose (Aguilar-Rivera, Rodríguez-Lagunes, & Castillo-Morán, 2010). For small peasant farms, a profitable alternative is natural brown sugar, for which production in Mexico fluctuates between 100 000 and 500 000 t year^{-1} (Méndez, Elorza, Maruri, Elorza, & Martínez, 2013). This enormous performance capability for a sugarcane multipurpose culture is highly important for its continued use, including its bio-factory potential for the synthesis of high-value sugars, biopolymers and pharmacological proteins (Gómez-Merino, Trejo-Téllez, & Sentíes-Herrera, 2014).

In Mexico, sugarcane agribusiness generates more than 930 000 direct jobs and 2.2 million indirect jobs, in 15 states and 227 municipalities (9.2% of all municipalities in Mexico) (Secretaría de Economía, 2012) that are grouped into six production areas (Northwest, Pacific, Center, Northeast, Gulf and South) (Aguilar-Rivera, Rodríguez, Enríquez, Castillo, & Herrera, 2012). In this value-chain, enormous strengths are related to soil quality and suitable climate where it is grown, and where the primary producer organizations and industry are well-structured, although complex. However, there are major challenges that need to be addressed to ensure a successful future for this value-chain. Recently, Aguilar-Rivera, Espinosa-López, Herrera, Castillo, and Lagunes (2013) performed an analysis of competitiveness of the Mexican sugarcane industry, taking into account Porter´s diamond model (Porter, 2008). Within this analysis, actor conditions; demand conditions; firm strategy, structure and rivalry; related and supporting industries; as well as role of the government and changes in the Mexican sugarcane value-chain are depicted. Herein, we further analyze more in-depth the state of the art for the sugarcane production system in Mexico, and describe its strengths and current and future challenges to ensure its consolidation through innovative strategies that may increase productivity and profitability.

2. History and Current Economic Importance of Sugarcane in Mexico

Since its introduction in Mexico nearly 500 years ago, sugarcane has become an integral part of the national economy. Although its development has gone through serious critical stages since its inception, it is now established as one of the most traditional agribusiness activities of significance in the country's economic development (Aguilar-Rivera, 2013), which now faces significant consolidation challenges to remain as an innovative and globally competitive value-chain.

The Mexican sugar industry has a historical-structural model depicting the operation of a traditional and rooted socioeconomic system after the triumph of the Mexican Revolution. This model is characterized by a supply of goods with low added value and low technology, coupled with a demand for high-technology goods and commercial value. This generates a trade deficit and an unfavorable environment for future sustainability.

The generation of Mexican varieties of sugarcane began in 1930, peaked in the 1970s, and in 1990 began to decline (Flores, 2001). Efforts coordinated by the National Chamber for the Sugar and Alcohol Industries (Cámara Nacional de las Industrias Azucarera y Alcoholera, CNIAA), the Center for Research and Development of Sugarcane (Centro de Investigación y Desarrollo de la Caña de Azúcar, CIDCA), the Secretariat for Agriculture, Livestock, Rural Development, Fisheries and Food (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, SAGARPA), the National Committee for the Sustainable Development of Sugarcane (Comité Nacional para el Desarrollo Sustentable de la Caña de Azúcar, CONADESUCA) and the sugarcane organizations National Confederation of Rural Holders (Confederación Nacional de Propietarios Rurales, CNPR) and the National Confederation of Farmers (Confederación Nacional Campesina, CNC), have maintained the agribusiness and are fundamental players for the increases observed to date.

Mexico is currently the sixth largest producer of sugar and sugarcane (FAOSTAT, 2013; ZAFRANET, 2013) which is not purely for export and the activity is based on domestic consumption (Aguilar-Rivera, 2012). The 2012/2013 harvest was conducted over an area of approximately 780 000 ha with 55 refineries in operation, and a production of 61.5 million tons of cane and a total of 6.7 million tons of sugar (CNPR, 2013; CONADESUCA, 2013). Apparent domestic consumption is more than 5 million tons of sugar per year with an annual per capita consumption of 47 kg (Aguilar-Rivera, 2012). Today, this agribusiness has an economic impact of approximately 2 591 million dollars, economically and socially impacting over 3 million Mexicans (Secretaría de Economía, 2012). In 2011, Mexico contributed 3% of the global sugarcane production (FAOSTAT, 2013).

In Mexico, the cultivation of sugarcane is concentrated in six regions (Figure 1): Northwest (state of Sinaloa), Pacific (states of Nayarit, Jalisco, Michoacán and Colima), Center (states of Puebla and Morelos), Northeast (states of Tamaulipas and San Luis Potosí), Gulf (states of Veracruz, Oaxaca and Tabasco) and South (states of Chiapas, Campeche and Quintana Roo) (CONADESUCA, 2013). The average yield of sugarcane was 66.10 t ha^{-1} for the 2010/2011 harvest, 65.87 t ha^{-1} for the 2011/2012 harvest and 78.74 t ha^{-1} for the 2012/2013 harvest, resulting in an average national yield of 70.2 t ha^{-1} for the last three harvest periods. Sugarcane harvesting in Mexico occurs over eight months, beginning in November and ending in June (Figure 1).

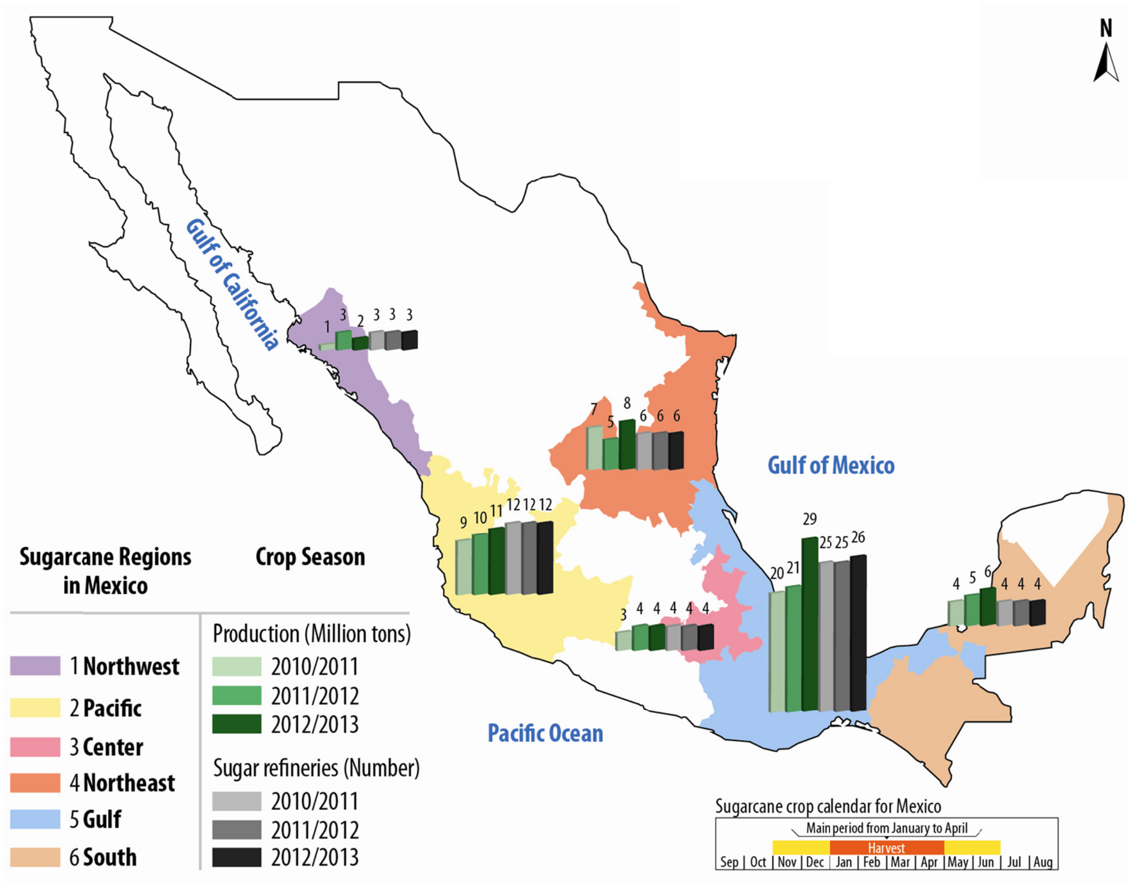

Figure 1. Mexican states where sugarcane is cultivated. Green columns represent sugarcane harvests in millions of tons, while the number of sugar refineries that operated are depicted by gray columns. Both indicators are shown for the last three harvest cycles: 2010/2011, 2011/2012 and 2012/2013. The six regions containing the 15 states where sugarcane is cultivated are shown in different colors (Sources: Blackaller, 2011; CNIAA, 2013; CONADESUCA, 2012, 2013)

The absence of a national model for diversification and management of information and knowledge on the subject are the primary obstacles to the consolidation of a sustainable, efficient and competitive sugarcane industry (Aguilar-Rivera, Galindo-Mendoza, Fortanelli-Martínez, & Contreras-Servín, 2011). This represents a great challenge, requiring the development of appropriate strategies to tap the full potential of sugarcane and the growth of internal and external markets, and will be affected by increased oil prices, and the appearance and demand for alternative sweeteners and biofuels which will increase pressure on the production systems, forcing them to seek innovative, sustainable and socially responsible alternatives for this value-chain (Gómez-Merino & Hernández-Anguiano, 2013). Although the last decade has seen a substantial increase in sugarcane production, as in 2012 when the area sown increased by 10% over the previous year, and similar growth is expected during the coming years (CNPR, 2013), there are still significant lags in the entire value-chain, ranging from the low education of producers and the low efficiency in government programs that support them, to an obsolete industrial infrastructure, inadequate regulation and a disadvantageous commercial system.

3. The Sugarcane Production System in Mexico

The sugarcane production system in Mexico is defined by many interacting economic, environmental and agronomic factors within each sugarcane region, as well as their magnitude and intensity.

3.1 Socio-Economic Factors

According to estimates (Secretaría de Economía, 2012), sugarcane production generates dividends of approximately 2591 million dollars (Table 1) and positively impacts the regions producing it, leading to a reduced rate of marginalization predominantly at the municipal level by decreasing the lags in income, increasing access to education, and providing more adequate housing and basic services (CONAPO, 2010a) (Figure 2).

Table 1. Economic and production indicators for sugarcane-producing states in Mexico by 2012

State	Area planted (ha)	Area harvested (ha)	Production (t)	Yield (t ha^{-1})	Price per ton (US$)	Production value (millions of US$)
Campeche	10 801.92	9 048.36	426 811.14	47.17	51.66	22.05
Colima	14 449.25	14 444.25	1 368 014.92	94.71	53.80	73.60
Chiapas	30 350.14	30 350.14	2 819 528.01	92.90	53.74	151.53
Jalisco	80 119.72	75 820.72	6 254 451.19	82.49	49.70	310.84
Michoacán	14 522.75	14 515.75	1 188 985.08	81.91	48.96	58.21
Morelos	16 275.00	16 275.00	1 927 773.75	118.45	61.18	117.94
Nayarit	33 441.34	32 596.44	2 247 524.54	68.95	57.31	128.80
Oaxaca	67 989.14	62 014.19	3 482 716.91	56.16	50.29	175.14
Puebla	12 137.65	12 137.65	1 777 437.47	146.44	55.38	98.44
Quintana Roo	28 421.00	28 421.00	1 682 523.20	59.20	35.86	60.34
San Luis Potosí	64 158.00	64 001.00	2 529 319.52	39.52	51.07	129.18
Sinaloa	23 586.48	20 418.54	1 777 638.09	87.06	50.25	89.32
Tabasco	29 112.00	28 705.00	1 780 571.15	62.03	47.46	84.50
Tamaulipas	62 038.00	55 841.00	3 571 590.36	63.96	54.54	194.78
Veracruz	289 840.32	270 537.64	18 112 495.00	66.95	49.47	896.02
National	777 242.71	735 126.68	50 964 485.13	69.33	50.85	2591.57

Source: SIAP, 2012.

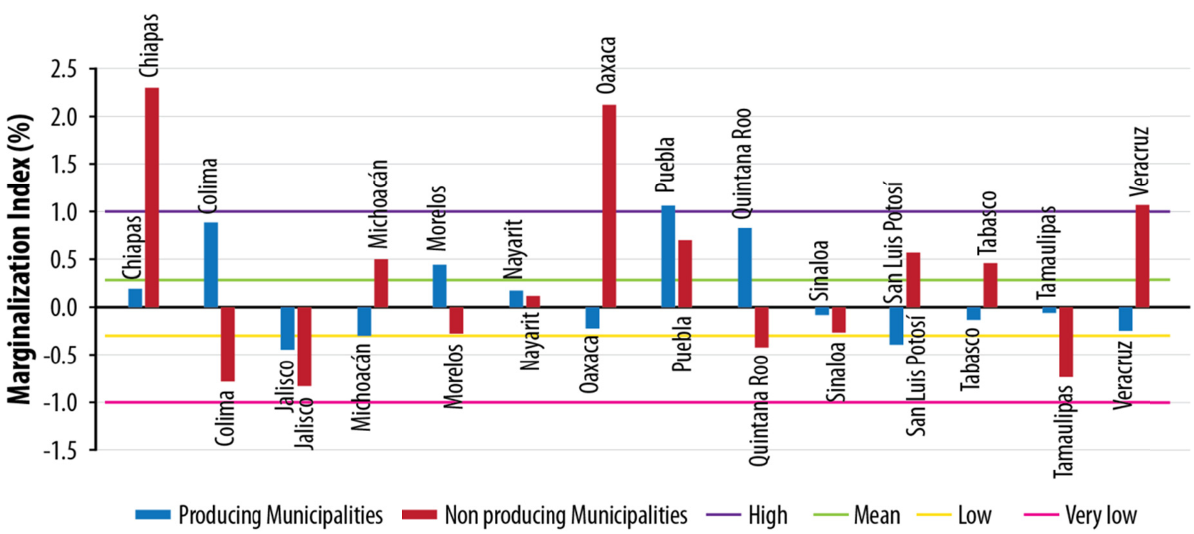

Figure 2. Marginalization indices for sugarcane producing (in blue) and non-producing municipalities (in red) among the 15 sugarcane-producing states in Mexico (Sources: CONAPO, 2010a, b; Secretaría de Economía, 2012)

Municipalities without sugarcane production are smaller than those producing sugarcane, with 80% of their populations living in towns with fewer than 5000 inhabitants, 60.7% of the inhabitants receiving less than two minimum wages and 23.8% without basic education (Secretaría de Economía, 2012), which puts them at a disadvantage. The more than 220 municipalities where sugarcane is produced are home to more than 12 million people, and their average contribution to national added value is 7.1% (INEGI, 2012; CONAPO, 2010a).

The diversification of the sugarcane agribusiness has been suggested as a strategy to increase profitability. However, according to Aguilar-Rivera (2012), such diversification could affect the supply of sugar and its market price due to competition for raw material (sugarcane) through simple fluctuation in supply and demand. Due to conflicts of interest, lack of strategic planning, dialogue, and consultation between the groups involved, diversification of this agribusiness has been only in political discourse. As such, alcohol production, for example, has fallen by roughly 80%, from 67 thousand liters of ethanol to only 14 thousand in the last decade, with only three refineries operating distilleries since 2010 (Secretaría de Economía, 2012).

Rather than relying on efficient and sustainable use of resources for production, sugarcane field dynamics respond to increases in harvested area, with a slight tendency for increases in yields. This behavior is a consequence of an unfavorable ratio between primary producers and the industry, as well as excessive government regulation that discourages competitiveness in the fields and factories. In addition, imports of high fructose corn syrup (HFCS) and other non-caloric sweeteners produced by high technology compete and displace domestic sugar production (Aguilar-Rivera et al., 2012; Secretaría de Economía, 2012). Indeed, in 2013, Mexico imported nearly 1300 thousand tons of HFCS from the USA (USDA, 2014), and the domestic market for this sweetener increases annually. In a recent study, Goran, Ulijaszek, and Ventura (2013) reported that countries with higher availability of HFCS have higher prevalence of type 2 diabetes. As in Mexico, there is a high prevalence of diabetes (14%), which is the leading cause of death in women and second in men (Sosa-Rubí, Galárraga, & López-Ridaura, 2009); HFCS poses a serious public health problem that must be properly managed.

Another socioeconomic factor determining the behavior of the system is land tenure. Of the total acreage devoted to this crop, 76.3% occurs in areas of 5 ha or less in suburbs and rural communities, while 18.8% is distributed in areas between 5.1 and 10 ha, and only 4.9% occurs in areas larger than 10 ha (Secretaría de Economía, 2012; INEGI, 2012). According to Pérez-Zamorano (2007) and Singelmann (2003), sugarcane small-holders and common lands, locally known as *ejidos*, and other socio-political phenomena in the field act as brakes on the sugar industry, separating land and capital, the two most important factors in terms of production agriculture and social welfare. Strategies such as digitizing sugarcane fields to improve agricultural precision have been undertaken by SAGARPA under the National Program for the Sugarcane Agroindustry (Programa Nacional de la Agroindustria de la Caña de Azúcar, PRONAC) and have provided important technological tools, but a joint effort to comprehensively address the multifaceted problems affecting this value-chain is still required, particularly in terms of land tenure and small-holders.

3.2 Environmental Factors

In Mexico, sugarcane production systems are located along the coasts of the Pacific Ocean and the Gulf of Mexico, in valleys of the Altiplano (high plateau), to southern Quintana Roo, where climates are varied. Historical records show 90% of the minimum monthly temperatures in sugarcane areas range from 10°C to 20°C from November to March. In contrast, the average monthly maximum temperature lies between 20°C and 30°C from December to February, increasing to more than 30°C between April and September (COLPOS, 2008; CONADESUDA, 2012).

Regarding irrigation, production is distributed with 62% in rainfed areas and the remaining 38% in irrigated areas (CONADESUCA, 2011a), with the average water consumption varying from 5.48 to 6.84 mm per day, which equates to 2000-2500 mm of rainfall per year. According to Moyer (2010), Mexico is the second-most vulnerable country to the effects of global climate change, with agricultural production possibly decreasing by more than 25% by 2080 if the country does not develop efficient strategies to adapt to this phenomenon. Growth in irrigation infrastructure is therefore critical to the success of this activity, as sugarcane cultivation is one of the most demanding for water and fertilizer. Advances in biotechnology, nanotechnology and precision agriculture are also required and Mexican institutions are making good progress in this regard.

Land for sugarcane production in Mexico has physical and chemical characteristics generally suitable for cultivation (COLPOS, 2008). Soils in cultivated areas are mainly classified as eutric fluvisol, vertisol eutric, cambisol endogleyic, eutric and chromic rendzic, and luvisol leptosol gleyic (Palma-López, 2009). The variation of some physical and chemical soil indicators are shown in Appendix A Table S1, which have direct or indirect relationships with the water catchment areas (rain and water storage capacity of the soil) (COLPOS, 2008).

Approximately 70% of the soils in sugarcane cultivation areas have nitrogen concentrations between 10 and 20 kg ha^{-1}, thus requiring the application of nitrogen fertilizers, 27.2% have phosphorous concentrations above 30 kg ha^{-1}, and 74% show potassium content higher than 160 kg ha^{-1}. Most of the soils dedicated to sugarcane cultivation (68.3%) show calcium levels between 2500 and 10 000 kg ha^{-1}, whereas magnesium ranges from 500 to over 1000 kg ha^{-1} on 65% of sugarcane land (detailed information in Appendix A Table S2) (COLPOS, 2008). Concentrations of the micro-nutrients Fe and Mn are high in most cases, even in areas with alkaline and calcareous conditions. Copper concentrations are mostly between 0.5 and 3 mg kg^{-1} of soil, while zinc is most often found in concentrations below 1 mg kg^{-1} of soil (COLPOS, 2008) (detailed information in Appendix A Table S3).

The general climate and soil characteristics in sugarcane producing areas indicate that conditions are favorable for crop development, and permit the identification of advantages and limitations (see Appendix A Table S4 for details). These data are crucial for making predictions about development, adaptability and crop production, as well as looking for new farmland. A projection for the areas with the greatest potential for expansion of sugarcane cultivation in Mexico shows that the current area devoted to this crop could grow to 5 million ha (with approximately 500 thousand ha showing high potential and 4.5 million ha with average potential) (SAGARPA, 2009).

3.3 Agronomic Factors

The National Program for High Sugarcane Profitability (Programa Nacional para la Alta Rentabilidad de la Caña de Azúcar, PRONAR, 2009) estimates that the low average productivity obtained over the last decade is due to ~~a~~ scarce use of emerging technology for water and soil analysis, as well as an inefficient soil management program, the lack of an effective national program for the generation and use of new varieties (efforts are made independently by each refinery), the absence of certified seed production systems, no national program coordinating the management and control of diseases, pests and weeds, and harvest management without quality controls. In addition, sugarcane in Mexico is grown in seven-year cycles, and the area planted is composed of 13% new plantings (1.5 years in age), 15% ratoons called *soca* (second crop from the same planting at 2.5 years old) and 72% of the ratoons known as *resoca* (third crop from the first planting, > 2.5 years of age) (Aguilar-Rivera et al., 2012), implying lower productivity for older plantations. Faced with this problem, the objective of PRONAR (2009) is to increase the profitability and competitiveness of Mexican sugarcane fields using the following ten steps: 1. Empowerment of farmers and smallholders; 2. Diagnoses limiting factors (water and soil); 3. Systematize tillage and soil preparation; 4. Schedule date and densities for seeding; 5. Select adequate seeds and varieties; 6. Apply balanced fertilization; 7. Manage water and wastewater properly; 8. Integrated management of pests and weeds; 9. Prepare systems for harvesting; and 10. Increase the capacity for mechanized harvesting. Although much to date has yet to be improved, PRONAR has facilitated the growth of production and productivity of sugarcane from its inception, as reflected in field and refinery yields.

3.3.1 Pest Management

The most important pests of sugarcane in Mexico are grass spittlebugs (various genera), stem-borers (various genera) and cane rats (various genera), which are distributed in all sugarcane cultivation areas (Flores, 2007). Spittlebugs cause losses ranging between 5 and 20 t ha^{-1} (CNPR, 2004). Methods of control include biological with the application of the fungus *Metarhizium anisopliae*, preparatory soil tillage, and chemical control (Toriello et al., 2008).

Regarding stem-borers, it is estimated that for every 1% increase in pest intensity, sugar losses are 5.8 kg ha^{-1} and with a decrease of 2 to 50% in yield (Aday, Barroso, & Izquierdo, 2003; Arredondo-Bernal & Rodríguez del Bosque, 2008), which also increases the incidence of fungal infections and contamination of juice (Hernández-Velázquez, Lina-García, Obregón-Barboza, Trejo-Loyo, & Peña-Chora, 2012). Integrated control of this pest consists of eliminating hosts in cultivation fields, preparatory soil tillage, and reducing insecticide use (Sánchez, 2005). Biological control includes the use of parasitoids and predators as natural enemies, such as: *Trichogramma atopovirilia*, *Chelonus sonorensis*, *Apanteles diatrea*, *Cotesia flavipes* and *Billaea claripalpis* (formerly *Paratheresia claripalpis*). As well, applications of the fungi *Metarhizium anisopliae* and *Beauveria bassiana* have been successful in managing pest populations (Arredondo-Bernal & Rodríguez del Bosque, 2008).

Cane rats are the most destructive pests of sugarcane plantations in the country, attacking approximately 30% of the cultivated area (Flores, 2007; CONADESUCA, 2013; Vásquez-López, Lorenzo-Monterrubio, & Bolaños-Citalan, 2013). It has been estimated that for every 1% of affected stems there is a reduction of 500 kg ha^{-1} of cane sugar. Additionally, there is an estimated loss of 2.2 kg per metric ton of sugar in the refineries for every 1% increase in damage intensity (Márquez, 2002; Flores, 2007). Methods of rodent control include cultural (based on modifying cane rat habitat using simple practices of weed control plots, dikes and irrigation canals) and biological, using birds of prey such as *Accipiter* spp., *Buteo* spp., *Aquila chrysaetos*, and snakes such as *Boa constrictor*, *Conopsis* spp., and *Crotalus* spp., achieving a 50% reduction in damage (Cervantes & Ballesteros-Barrera, 2012; Vásquez-López et al., 2013).

The primary pests, parasitoids and predators of insects in Mexican sugarcane cultivation are listed in Appendix A Table S5, while plant protection products authorized for control appear in Appendix A Table S8.

3.3.2 Disease Management

In Mexico, 55 plant diseases have been reported, 22 from parasites and 33 from non-parasites (Chinea-Martín & Milanés-Ramos, 2006). Among the most important diseases are rust, smut, mosaic and scald (CONADESUCA, 2011b). In addition to the genetic resistance provided by sugarcane varieties, use of pathogen-free seed has been implemented to prevent the spread of diseases. Heat treatments and tissue culture are disinfection methods that ensure plant health and seed cane. Although disease control in commercial sugarcane fields in Mexico is not a common practice, with the recent detection of orange rust [*Puccinia kuehnii* (W. Krüger) E. J. Butler] in the country, the National Service of Health, Food Safety and Quality (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria, SENASICA) has registered various fungal control products (SENASICA, 2011) (Rebollar-Alviter, Sánchez-Pale, & Silva-Rojas, 2012). The major diseases of sugarcane in Mexico are listed in Appendix A Table S6.

3.3.3 Weed Management

Control of unwanted vegetation or weeds is an essential practice in the early stages of sugarcane development, because if not controlled in a timely fashion, they can cause losses in crop productivity between 10 and 84% (Cruz, 2009). The most harmful weed species belong to the families Poaceae and Cyperaceae (order Poales), but species of the genus *Ipomoea* spp. (order Solanales; family Convolvulaceae) also interfere with sugarcane plant development (CONABIO, 2012). The use of herbicides (chemical control) is the most common form of weed control in most cultivation areas around the world. In Mexico, the most widely used herbicides are ametrine and diuron, which are recommended for postemergence application and have a residuality of one to two months, depending on moisture and soil type (Esqueda, 1999). A list of major weeds found in sugarcane cultivation areas in Mexico appears in Appendix A Table S7, whereas authorized control products that are registered with SENASICA (SENASICA, 2011) and permitted for use in the cultivation of sugarcane in Mexico are listed in Appendix A Table S8. The use of different organisms and natural active substances for the management and control of sugarcane pests are also being investigated (Arredondo-Bernal & Rodríguez del Bosque, 2008; CONABIO, 2012; Salgado-García et al., 2013).

4. Structure of the Mexican Sugar Agribusiness System

The Mexican sugarcane production system is a mosaic of cultural, social, political, economic, technical and educational factors that limit and slow rural development and industrial sugarcane production. To solve this problem, it is necessary to begin with the primary sector, the field, which is characterized by low income and yield per unit of production; poor agronomic practices; small cultivation areas (3 ha per producer on average); resistance to technological change because of cultural values and beliefs; complex social relationships; lack of enforcement of regulations and phytosanitary protocols; and organizational structures that maintain the damaging cycle of low production - low income - poverty - social, economic, environmental and political marginalization (Aguilar-Rivera, 2013). A recent analysis, however, shows that there are three determinants of sugarcane productivity: field performance and agribusiness, credit and irrigation, which contrast with the prioritization of needs for research-development-innovation that producers have been proposing: generation of new varieties, pest and disease control (CONADESUCA, 2013).

Currently there is a certain dynamic of transformation and modernization, not only to make this activity more productive, but also to address the challenges of climate change and globalization, including the use of new technologies, machinery and modern equipment, and considering environmental, employment and social sustainability indicators as well. However, these initiatives are erratic and inconsistent over time, restricting the consolidation of global competitiveness of the agribusiness system, which in terms of creating value is the second largest in the country, just after the maize value-chain (Aguilar-Rivera et al., 2012).

In terms of operational structure, the 55 sugar refineries currently operating in Mexico belong to 14 industrial groups, while six refineries are independent (for details see Appendix A Table S9) (MAM, 2013). Of the total, 76% of the sugar is in the hands of private business, while the remaining 24% is under federal control.

Sugar productivity is highly variable and generally uncompetitive. For example, in the last harvest (2012/2013) the average supply ranged from 53.8 t ha^{-1} in Aszuremex Tenosique (Tabasco) to 125.8 t ha^{-1} in Tamazula (Jalisco), yielding a national average of 78.7 t ha^{-1}. In the previous harvest (2011/2012), the lowest yield was 35.9 t ha^{-1} from the refinery in Alianza Popular (San Luis Potosí) and the highest was 121.4 t ha^{-1} from Atencingo (Puebla), yielding a national average of 65.8 t ha^{-1} (CONADESICA, 2012, 2013) (a detailed analysis of the past 30 years is discussed later). This dichotomy between low and high productivity is due to differences in the size and capacity of the refineries, refinery age and level of technology, with a predominance of medium and small refineries, having an average age of 77 years, with obsolete and inefficient technologies, which increase production costs and decrease productivity. In addition, this value-chain is facing serious problems from environmental impact and is being severely criticized because it occupies large tracts of fertile land that could be used for the production of basic grains, accelerates deforestation and land degradation, forms implicit monocultures, contaminates or pollutes soils, surface and groundwater and air through the indiscriminate use of fertilizers, pesticides, herbicides, molasses, other waste products and the burning of cane fields prior to harvest (Aguilar-Rivera et al., 2012). Also common in this system are low seasonal wages, excessive working hours under deplorable conditions, and the employment of children and women in risky work. In fact, in Mexico there is no systematized project that has had sufficient time to develop human capacity at any stage of the value-chain. On average, 71% of the rural producers have only a basic education (six years of primary school) and 18% cannot read or write (Aguilar-Rivera et al., 2011), which further hinders constructive change.

5. Legislation and Organizations in the Mexican Sugar Industry

The legal framework supporting and regulating the sugar industry in Mexico is complex and extensive, and consists of the following contracts, laws and agreements: Ley de Desarrollo Rural Sustentable, Ley de Desarrollo Sustentable de la Caña de Azúcar, Programa Nacional de la Agroindustria Cañera 2007-2012, Ley de Promoción y Desarrollo de los Bioenergéticos, Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética, Contrato Ley de la Agroindustria Azucarera y Alcoholera, Ley del Seguro Social, Ley Federal del Trabajo and international free commerce (Blackaller, 2011). Derivatives of the Ley de Desarrollo Sustentable de la Caña de Azúcar (LDSCA, 2005), the National Program for the Sugarcane Agroindustry (PRONAC, 2007) and the Acuerdo para la Modernización de la Agroindustria de la Caña de Azúcar are intended to provide greater certainty for this national industry for the buying and selling, planting, cultivating, harvesting, delivering and receiving of sugarcane (Blackaller, 2011; CONADESUCA, 2013).

Sugar industry organizations perform specific functions that benefit this value-chain, and include: CONADESUCA, CNIAA, the National Association of Sugar Companies (Asociación Nacional de Empresas Azucareras, A.C., ANEA), the Mexican Association of Sugar Technicians (Asociación de Técnicos Azucareros de México, A.C., ATAM), the Mexican Union of Sugarcane Workers (Sindicato de Trabajadores de la Industria Azucarera y Similares de la República Mexicana, STIASRM), CNPR, the National Union of Sugarcane Growers (Unión Nacional de Cañeros, UNC), the National Union of Sugarcane Producers (Unión Nacional de Productores de Caña de Azúcar, UNPCA), and the Mexican Regional Workers Confederation (Confederación Regional Obrera Mexicana, CROM).

6. Agricultural Insurance for Sugarcane in Mexico

As a consequence of climate change, drought in Mexico causes 80% of the agricultural losses, while severe weather (e.g. storms, cyclones and hurricanes) contribute 18% of the damage (AGROASEMEX, 2006). In 2012, nearly 12 million hectares of national agriculture (54% of the cultivated area in the country) benefited from some form of insurance (SIAP, 2013). In Mexico, 80% of the insurance is concentrated on only four crops: corn, sorghum, wheat and sugarcane, and of this amount, 76.4% are operated by government insurance funds and 23.6% by private insurers.

Insurance for sugarcane represents 14% of the total agricultural area secured in Mexico, and 91.2% of the insurance is provided by private companies (AGROASEMEX, 2013). The 14 thousand hectares of sugarcane affected each year represent losses of 15.1 million dollars annually (Rivera, 2012). Currently, of the more than 780 000 ha planted with sugarcane in Mexico, 321 000 ha are insured, which represents 41% of the total area planted with sugarcane (AGROASEMEX, 2013).

7. Historical Productivity of Sugarcane and Sugar in Mexico

The Mexican sugar industry has had irregular development over the last thirty years, and the number of refineries has declined from 67 in 1980 to 55 at the close of 2013. In contrast, during this same period (1980-2013), the area planted increased by 39%, productivity of supply areas grew by 17%, factory efficiency improved by 19%, and sugar production grew by 62% (Figures 3, 4). The relative gains were due to factors related with government subsidies (8% of the total national agricultural subsidies), and some recent efforts to increase productivity through support for training, digitization and systematization of processes, and modernization of the production equipment for at least 40% of the refineries and their supply areas.

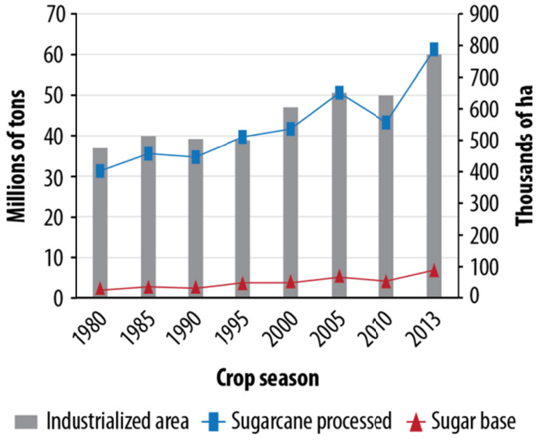

Figure 3. Total sugarcane production and surface area planted during the last three decades in Mexico (Source: MAM, 2013)

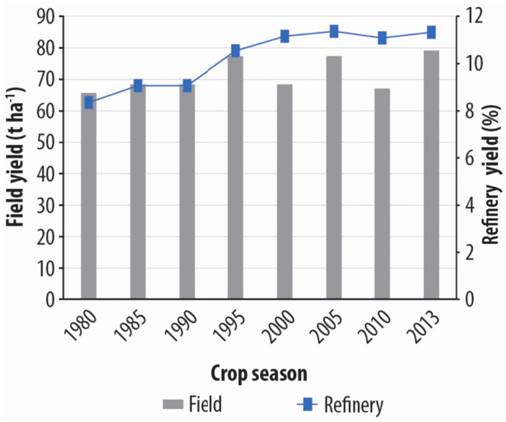

Figure 4. Sugarcane production in the fields and factories during the last three decades in Mexico (Source: MAM, 2013)

Despite this upward trend in absolute terms, and accounting for figures, improved productivity indicators are modest. For example, while in Mexico the average field harvest during the last three harvest periods (2010/2011, 2011/2012 and 2012/2013) was 70.2 t ha^{-1}, in other Latin American countries such as Guatemala, Colombia and Peru, yields exceeded 100 t ha^{-1} (Secretaría de Economía, 2012). As for Mexico, these increases have been based largely on government subsidies and increased plantings, rather than in process efficiency.

8. Government Support for Sugarcane Research

The technology used in the fields and refineries is mostly provided by other countries, and investment in scientific research, technological development and innovation (R+D+I) is sparse and erratic because Mexico spends only 0.49% of its GDP on R+D+I, with only $200 million dollars invested annually on agricultural research (CONACyT, 2012; OECD, 2013). Private resources for scientific research in this value-chain are limited, while the government only in the last three years (2011-2013) had a spike of $14.4 million dollars, and a total of $20.8 million dollars allocated between 2003 and 2013 (Figure 5).

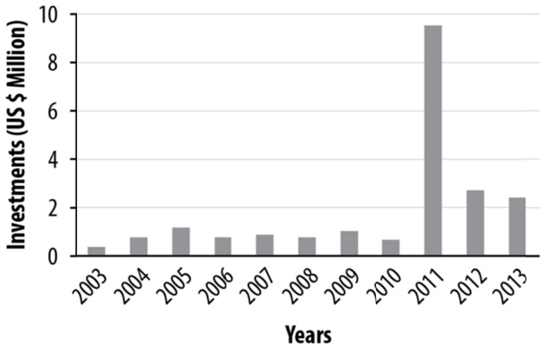

Figure 5. Government funds destined for sugarcane research in Mexico during 2003-2013 (Sources: CIDCA, 2013; SNITT, 2013)

In Mexico, less than 1% of the sugarcane cultivation area is dedicated to scientific experimentation and there is only one breeding program with very uncertain economic resources (Quintero-Núñez, 2012). This program is supported by government and producers through CONADESECA, which emphasizes the main priorities of innovation and technology transfer as: generation of new varieties, management and control of pests and diseases, and agricultural components of technology in irrigation and fertilization according to the demand of the Committee for Sugarcane Production and Quality (Comités de Producción y Calidad Cañera, CPCC) (CONADESUCA, 2011b). This prioritization, however, does not attend to important issues such as adaptation to climate change and efficient water use, topics of primary importance to Mexico due to the vulnerability of agricultural regions (Moyer, 2010).

Importantly, in 2013, the federal government, through SAGARPA, approved an emergency program in the amount of $115 million dollars for sugarcane production, whose objective is to enhance sugarcane productivity in the country (Blackaller, 2013).

9. Genetic Improvement of Sugarcane in Mexico

The sugarcane genetic improvement program represents a coordinated effort among eleven Regional Experimental Stations (Campos Experimentales Regionales, CERs), as well as quarantine and hybridization stations (Figure 6). The Hybridization Station is located in Tapachula, Chiapas (housed within CIDCA), whose geographical location provides excellent natural conditions to obtain Fuzz (seeds) of high quality and viability. There is a germplasm bank housing 2768 varieties, of which 250 are classified by sex and can be found in the Plant Breeding Center (Banco de Cruzamientos), crosses which are conducted every year for different agroecological zones in Mexico and for international commitments (CIDCA, 2013). The National Sugarcane Quarantine Station (Estación Nacional Cuarentenaria de la Caña de Azúcar, ENCCA) is located in Tizimín, Yucatán, where genetic material received from other countries is evaluated for 18 months to confirm that it is not contaminated. This clean material is sent to different CERs in the country and to CIDCA. The CIDCA Germplasm Bank enters only those genotypes that present outstanding characteristics as parent stock to continue the hybridization program (Flores, 2012).

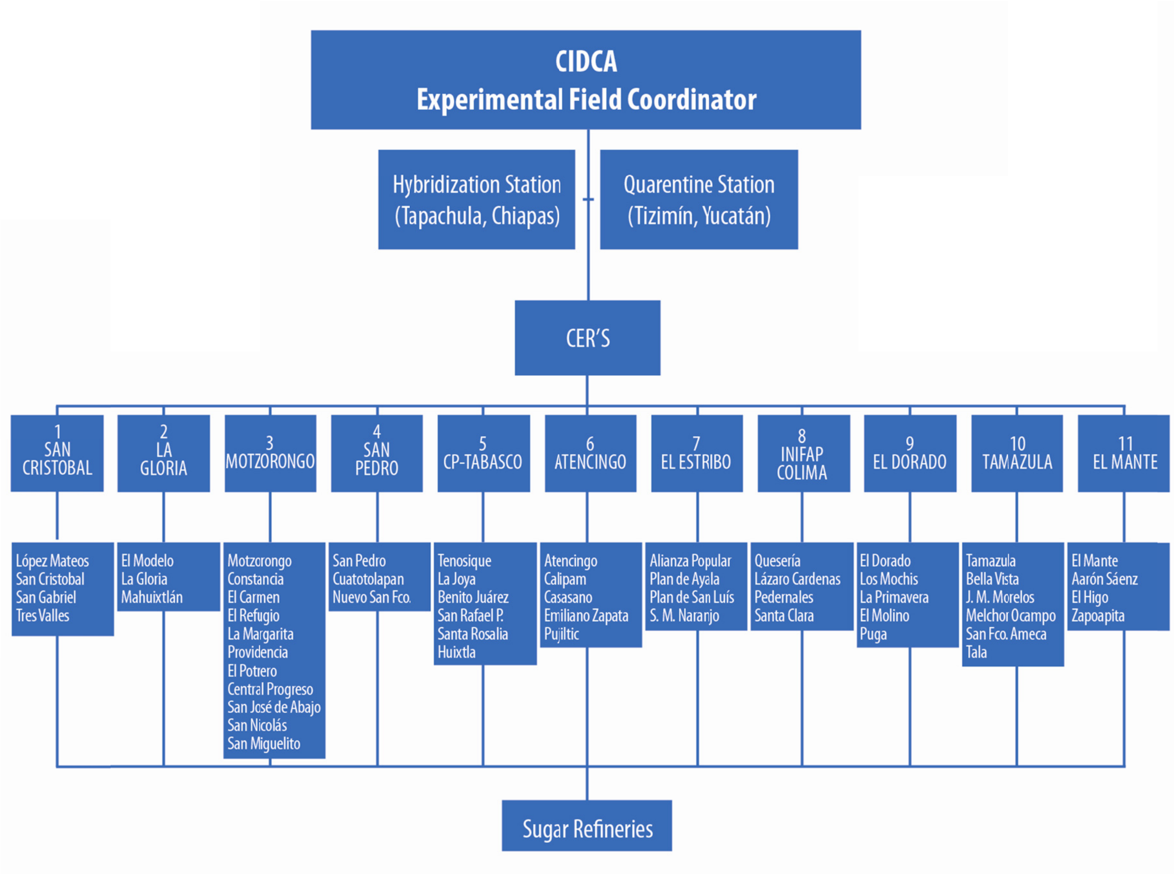

Figure 6. Coordination of the breeding and selection program for sugarcane varieties in Mexico. CIDCA contains many Regional Experimental Centers (Centros Experimentales Regionales, CERs) and each CER serves a number of sugar refineries

The selection process consists of the following phases: seedling, row, stump, plot, Multiplication I, adaptability test, Multiplication II, agroindustrial evaluation, Multiplication III, semi-commercial and seed testing. This process makes available one to four varieties every 14-16 years (for details see Appendix A Table S10) (IMPA, 1983; Flores, 2001).

9.1 Current Developments in Genetic Improvement of Sugarcane in Mexico

Since 1952, the work performed in the Hybridization Station in CIDCA has allowed for the release of 150 Mexican varieties, which occupy 55% of the sown area in the country; the remaining 45% is planted with foreign varieties from the National Program for Exchange and Import of Sugarcane Varieties maintained by CNIAA (CIDCA, 2013). The best performing Mexican varieties are: Mex 69-290, Mex 79-431, ITV 92-1424, Mex 68-P-23, Mex 57-473, ATEMEX 96-40, Mex 69-749, Mex 68-1345, Mex 55-32, Mex 73-1240 and Mex 80-1410, while the most important foreign varieties are: CP 72-2086, RD 75-11, My 55-14, NCo 310, SP 70-1284, Co 997, L 60-14 and CP 44-101 (MAM, 2013). Thanks to the genetic improvement program, sugarcane production and productivity has been increasing and it is estimated that yields have grown annually by 0.4%. However, compared to the yield increases in Brazil, which have reached 1.5% *per annum* (Waclawovsky et al., 2010), the gains in Mexico are modest. Moreover, in 1980, nine varieties occupied 70% of the cultivated area, while in 2013 this number was reduced to three varieties (Mex 69-290, Mex 79-431 and CP 72-2086) that occupy the same percentage of acreage (Figure 7). This indicates that the improvement program in the country needs to expand its genetic base, given the tendency toward greater homogeneity of the materials that make the system vulnerable to abiotic and biotic factors (Alejandre-Rosas, Galindo-Tovar, & Lee-Espinoza, 2010; González-Jiménez, Valdez-Balero, Gómez-Merino, Silva-Rojas, Pérez-Flores, & Ortiz-García, 2011).

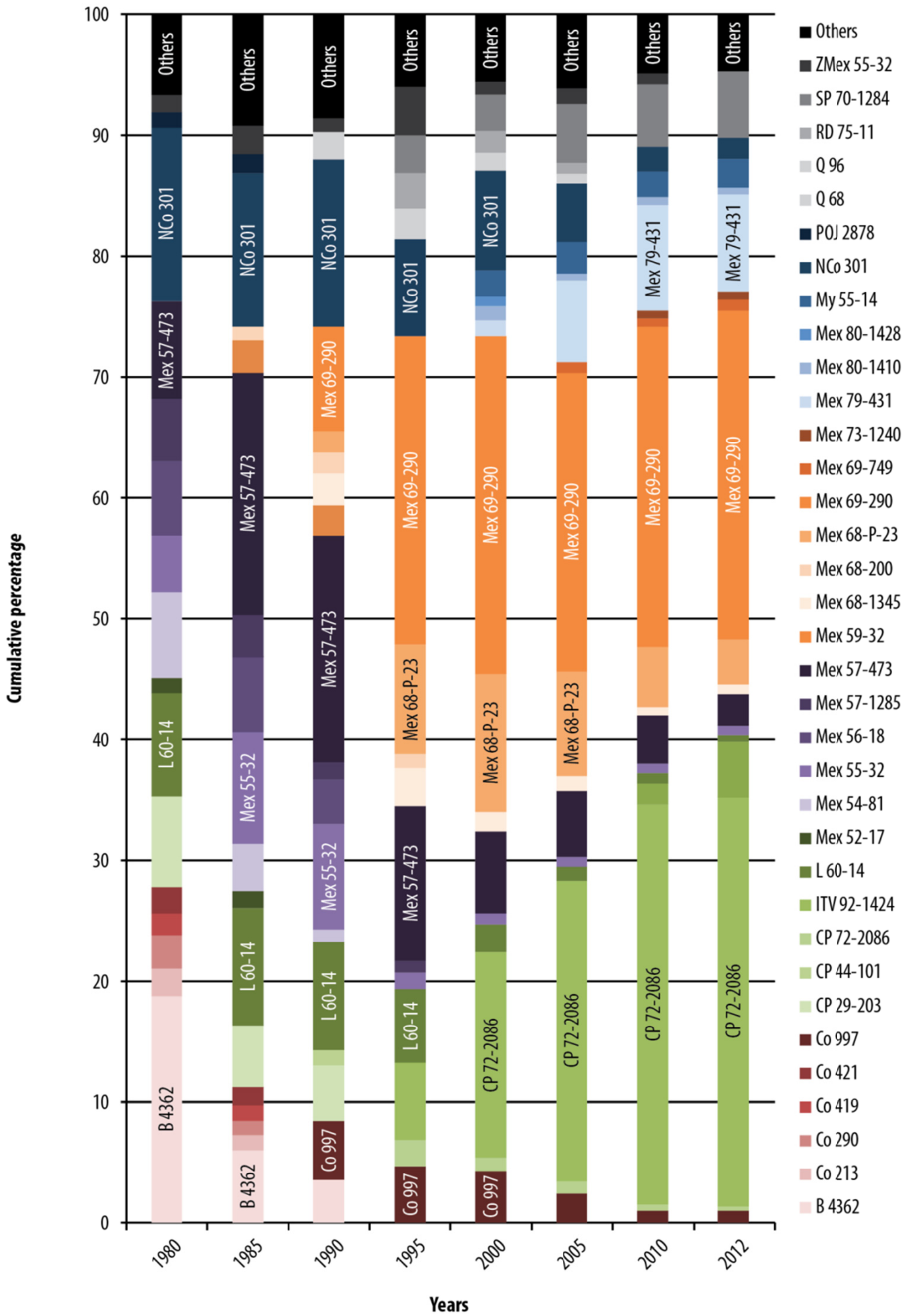

Figure 7. Percentage distribution of foreign and domestic sugarcane varieties in Mexico from 1980 to 2012 (Sources: CNIAA, 2013; MAM, 2013)

In terms of scientific capacity, Mexico has a significant infrastructure, research laboratories and centers of investigation with a scientific base of over 5000 researchers, and the enrollment of students in agricultural sciences in the country amounts to more than 44 000 (CONACyT, 2012; ANUIES, 2012; OECD, 2013), which is one of the greatest advantages in meeting the needs of innovation for genetic improvement and in other field and factory processes within this value-chain.

10. New Guidelines in the Sugarcane Value-Chain

Based on the Porter´s diamond model (Porter, 2008), Aguilar-Rivera et al. (2013) described the constraints on factor conditions including the high rainfed sugarcane producing areas (more than 60% of the total), migration and low-qualified labor market, an extraordinarily low R+D+I investment percentage compared with other countries, pre-harvest burning and air pollution, stagnating low sugarcane and sucrose yields, high production costs, byproduct production is not included in the final value of the industry as a whole, and the value-chain is concentrated only on three main products: sucrose, molasses and bagasse. Demand conditions limiting elements encompass a primary domestic market of sugar (75% of the sugar produced inland is consumed domestically), byproducts are not industrialized, a dramatic reduction of ethanol production (78.4%), while HFCS imports are significantly increasing. Concerning related and supporting industries, fewer refineries have certified processes, sugar production relies upon a few varieties, byproducts are not efficiently commercialized, ethanol and energy cogeneration are limited, and networks for R+D+I are lacking. As for the strategy, structure and rivalry, the private sector operates 76% of the refineries and the remaining 24% is operated by the government *via* the Fund of Expropriated Companies from the Sugar Sector (Fideicomiso para la Expropiación de Empresas del sector Azucarero, FEESA), the market is more focused on the offer instead of demand, product differentiation is scarce, and there is a general weakness of the system because of the lack of international competitiveness (the economic health of the system depends on domestic consumption and prices). The government controls the system by regulating prices of raw material and sugar, but has not created a good environment to make the sector competitive and an efficient infrastructure is lacking. Furthermore, the international crisis has not served as a catalyzer for the industry, whereas the country has no diversification programs and new niche markets are not well-designed.

One of the first guidelines for improving the competitiveness of the sugarcane value-chain is to increase human capacity through the development of knowledge and skills for all actors involved, but mainly for primary producers and field technicians. The latter should be continual and consolidate the management training program for information and communication technologies (ICT) for which SAGARPA began in 2008, but has not continued.

While Mexico has the capacity to increase up to seven times the area for sugarcane harvesting (from the current 800 000 to 5 million ha), this growth must be accompanied by good planning for the raw material (food, bioenergy, chemical industry), because refineries have not been modernized and the number of distilleries for ethanol has decreased significantly. The greatest potential for such growth is in the states of Chiapas, Jalisco, Morelos and Puebla, while refineries in the states of Campeche, Tabasco and San Luis Potosí would have to redesign their operations due to their lower productivity associated with agronomic-technical, environmental and socioeconomic limitations.

Analyses of the last production cycles (2000 to date) show that field performance has been irregular and, with the exception of the last harvest (2012/2013), the indicator has been declining. Points to address in this respect are associated with the limiting factors already described for the field, but also the possibility of increasing industry competitiveness using different strategies that involve increased performance in the field and refineries for access to credit and surface irrigation. Providing basic products, co-products, byproducts and derivatives for industries as varied as food, health, agriculture, chemistry, energy, transportation, housing and construction, are alternatives that have yet to be analyzed by decision-makers, producers, industries, scientists and academics, in order to take advantage of opportunities involving economic liberalization and industrial growth of the country.

Because internal situations cause lags in the field and refineries and low investment in R+D+I, it is necessary to rethink policies and strategies to improve the current system and successfully develop skills and potentials. Generation of domestic technologies, sustainable development of production processes and social responsibility, implementation of communication and information technologies, nanoscience and biotechnology and studies of domestic and global markets, are some of the suggested guidelines for achieving these tasks. Currently, Mexico has the capacity to develop projects for genome and metagenome sequencing, which opens up great possibilities for promoting development of this value-chain.

Thus, the new sugarcane production system in Mexico should be approached using holistic, inter- and transdisciplinary methods. The development of teams with complementary skills and knowledge (producers, industry, policy-makers, scientists and academics from different disciplines) will be critical for the success of these strategies. In work schedules, it will be necessary to develop educational programs, increase human development and knowledge management in the first hierarchical level, primarily for the less-educated producers so that it acts as a trigger for change in the management process. From there, and in accordance with PRONAR, it will be necessary to continue with technical aspects such as the diagnoses of soil conditions and limiting climatic factors;

tillage and conservation of soil and water; dates and densities of planting; generation and selection of varieties and the production of adequate seed; proper management of crop nutrition (fertilization); integrated management of diseases, pests and weeds; as well as mechanized and green harvesting. A similar work schedule could be applied in the refineries, so that process management innovations are completed, including technological, organizational and commercial forms.

11. Conclusions

Sugarcane is a crop with great potential for growth in Mexico because of its potential to achieve more than 800 t ha^{-1} of fresh matter, compared to a current average value of 70 t ha^{-1}. Projections for land use predict that sugarcane cultivation in the country could expand to 5 million hectares.

Mexico has important scientific infrastructure, but it is not sufficient to meet the demands of many branches of the industry, so it will be necessary to increase public and private investments which are currently scarce and irregular. Among the priority issues to address is capacity-building for all actors involved in the value-chain, but primarily for producers with lower educational levels, and to continue to work on strengthening programs that generate new varieties (broadening the genetic base) capable of producing even under adverse conditions from climate change, improving agronomic practices for water management and crop nutrition (balanced fertilization based on studies of plant needs), expanding the system of recruitment and use of water and irrigation, continuing the search for sustainable strategies for the integrated management of disease-causing pathogens, pests and weeds, increasing mechanized and green harvesting, improving distribution from the supply areas to make more efficient use of transportation and fuel and of advances in information and communication, including, if possible, improvements in process automation. The diversification of the value-chain is an alternative that could increase the profitability of this activity, but it must be implemented using efficient planning and negotiation with the actors involved. To increase yields in fields and refineries, increased access to credit and irrigation infrastructure are critical. Concerning factor conditions, generation of new varieties, increases in productivity (both in cane and sucrose), diminishing production costs, sustainable and efficient use of water, green harvest, recycle of agricultural residues, digitizing sugarcane fields to improve agricultural precision, and converting conventional sugarcane mills into biorefineries to produce many value-added products such as glycerol, bioethanol, inositol, carbon dioxide, and succinic acid, would be among the actions to be implemented in order to improve the national sugarcane value-chain competitiveness. As for demand conditions, self-sufficiency for both sucrose and ethanol, diversification of white and brown sugars, using bagasse to fuel and cogenerate steam and electricity, carbon sequestration and carbon credits for clean development mechanisms, animal feed and supplements, high-value niche markets with a variety of novel products, and organic soil amendments need also to be approached. Furthermore, inputs, machinery, technology and services, energy and other sales of byproducts, inter-industry cooperation at national and international scales, as well as logistic operations must be taken into consideration in relation to similar and supporting industries. Finally, regarding firm strategy, structure and rivalry, the Mexican sugarcane production system must consider human resources to further education and technical training, technical assistance, process certification, wastewater treatment, integration and company management, farmer organization and prospective analyses, which are the primary actions to be carried out in order to reach competitiveness expectations. As well, by recognizing the importance of development of adequate infrastructure for sustaining growth and to ensure inclusiveness of the growth process, the government will continue to play a lead role in infrastructure development, as well as in legislation, establishment of new biorefineries, free trade agreements, competitive environments, R+D+I, regional clusters and access to information. Last, the Mexican sugarcane agro-industrial system has opportunities related to geographical location, emergence of new markets, bioenergy needs and a growing trend of cooperative relationships between private companies and universities.

The sugarcane value-chain is the second largest in the country, and is strategic in the generation of jobs, alternative energy, and substrates for other industries such as pharmaceutical, sucrochemistry and new approaches such as novel bio-factories. In order to make the Mexican sugarcane system a globally competitive one, the current crisis in this value-chain demands considerable effort from all stakeholders, including education and human development, while considering current and future technological advances.

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APPENDIX A Supplementary Material

Table S1. Physical and chemical soil indicators and the percentage coverage in the areas supplying sugar refineries in Mexico

EC		pH		OM		IA		Clay		WR	
dS m^{-1}	%*	Value	%*	Content	%*	cmol kg^{-1}	%*	Percent content	%*	Percent	%*
<1.0	91.3	<4.5	6.5	<1.0	5.5	0.0	65.1	<10	2.2	1	77.8
1.0-2.0	5.9	4.6-5.5	16.6	1.0-2.0	17.7	0.01-0.10	11.6	10-20	12.2	2	4.0
2.1-3.0	2.7	5.6-6.5	21.9	2.1-3.0	27.0	0.11-0.20	6.2	21-30	18.7	3	7.2
3.1-5.0	7.1	6.6-7.5	18.6	3.1-5.0	37.2	0.21-0.40	4.4	31-40	20.8	4	6.2
>5.1	0.1	>7.6	36.4	>5.1	12.6	>0.41	12.6	>41	46.0	5	4.9

Source: COLPOS (2008). EC: Electrical conductivity; OM: Organic material; IA: Interchangeable acidity; WR: Waterlogging risk.

* Percentage values are for the surface area having the given characteristic with regard to the total area devoted to sugarcane production in Mexico.

Table S2. N, P, K, Ca and Mg concentrations in soils from lands supplying sugar refineries in Mexico

Nitrogen		Phosphorous		Potassium		Calcium		Magnesium	
kg ha^{-1}	%*	kg ha^{-1}	%*	kg ha^{-1}	%*	kg ha^{-1}	%*	kg ha^{-1}	%*
<10	6.7	<5	29.4	<40	0.2	<250	0.2	<50	0.1
10-20	68.5	5-10	16.2	40-80	6.2	250-2500	22.1	50-100	1.1
21-30	14.7	11-15	9.9	81-120	12.3	2501-5000	34.7	101-500	33.5
31-50	7.4	16-30	17.3	212-160	7.4	5001-10 000	33.6	501-1000	26.6
>50	2.7	>30	27.2	>160	74.0	>10 000	9.4	>1000	38.7

Source: COLPOS (2008).

* Percentage values indicate the surface area having the given characteristic with regard to the total area devoted to sugarcane production in Mexico.

Table S3. Concentrations of Fe, Cu, Zn and Mn from supply area soils for sugar refineries in Mexico

Iron		Copper		Zinc		Manganese	
mg kg^{-1}	%*	mg kg^{-1}	%*	mg kg^{-1}	%*	mg kg^{-1}	%*
<0.5	1.0	<0.5	40.7	<0.5	54.7	<0.5	1.8
0.5-1.0	0.2	0.5-1.0	7.6	0.5-1.0	12.1	0.5-1.0	0.2
1.1-3.0	0.6	1.1-3.0	31.4	1.1-3.0	18.7	1.1-3.0	1.9
3.1-5.0	1.0	3.1-5.0	9.6	3.1-5.0	7.2	3.1-5.0	1.3
>5.0	97.2	>5.0	10.8	>5.0	7.3	>5.0	94.8

Source: COLPOS (2008).

* Percentage values are for the surface area having the given characteristic with regard to the total area devoted to sugarcane production in Mexico.

Table S4. Primary climate and soil characteristics of the six sugarcane production regions in Mexico

Region	State	Predominant Climate	Mean Annual Temperature and Precipitation	Predominant Soils
Northwest	Sinaloa	Hot sub-humid: 48% Dry and semi-arid: 40% Very arid: 10% Temperate sub-humid: 2%	Mean: 25 °C Maximum: 36 °C Minimum: 10.5 °C Precipitation: 790 mm	Cambisol Calcic kastanozem Phaeozem Regosol Vertisol
Pacific	Nayarit	Hot sub-humid: 91.5% Temperate sub-humid: 6% Dry and semi-arid: 2% Hot humid: 0.5	Mean: 25 °C Maximum: 35 °C Minimum: 12 °C Precipitation: 1100 mm	Humic acrisol Hortic acrisol Humic andosol Dystric cambisol Eutric cambisol Humic cambisol Haplic phaeozem Vertic gleysol Chromic luvisol Hortic luvisol Eutric regosol
	Colima	Hot sub-humid: 86% Arid and semi-arid: 12.5% Temperate sub-humid: 1.5%	Mean: 25 °C Maximum: 30 °C Minimum: 18 °C Precipitation: 900 mm	Humic andosol Eutric cambisol Ferric cambisol Haplic phaeozem Lithosol Haplic luvisol Chromic regosol Eutric regosol Pellic vertisol
	Jalisco	Hot sub-humid: 68% Temperate sub-humid: 18% Arid and semi-arid: 14%	Mean: 20.5 °C Maximum: 23 °C Minimum: 7 °C Precipitation: 1000 mm	Humic andosol Chromic cambisol Ferric cambisol Eutric cambisol Calcaric phaeozem Haplic phaeozem Fluvisol Lithosol Haplic luvisol Chromic luvisol Eutric planosol Luvic planosol Chromic regosol Eutric regosol Calcaric regosol Dystric regosol Eutric regosol Chromic vertisol Pellic vertisol
	Michoacán	Hot sub-humid: 54.5%	Mean: 20 °C	Chernozem

		Temperate sub-humid: 29% Arid and semi-arid: 15% Temperate humid: 1% Hot humid: 0.5%	Maximum: 31 °C Minimum: 8 °C Precipitation: 850 mm	Kastanosem Podzol
Center	Morelos	Hot sub-humid: 87% Temperate humid: 11% Temperate sub-humid: 2%	Mean: 21.5 °C Maximum: 32 °C Minimum: 10 °C Precipitation: 900 mm	Fluvisol Kastanozem Chernozem Haplic phaeozem Lithosol Vertisol
	Puebla	Temperate sub-humid: 35% Hot: 25% Arid: 19% Temperate humid: 7% Cold: 0.2%	Mean: 17.5 °C Maximum: 28.5 °C Minimum: 6.5 °C Precipitation: 1270 mm	Cambisol Phaeozem Fluvisol Lithosol Luvisol Regosol Vertisol Xerosol
Northeast	Tamaulipas	Hot sub-humid: 58% Arid and semi-arid: 38% Temperate sub-humid: 2% Hot humid: 2%	Mean: 22 °C Maximum: 23.5 °C Minimum: 10 °C Precipitation: 780 mm	Eutric fluvisol Lithosol Rendzic Pellic vertisol
	San Luis Potosí	Arid and semi-arid: 71% Hot sub-humid: 15% Hot humid: 10% Very arid: 2.5% Temperate sub-humid: 1.5%	Mean: 21 °C Maximum: 32 °C Minimum: 8.4 °C Precipitation: 950 mm	Lithosol Calcaric regosol Rendzic Pellic vertisol
Gulf	Veracruz	Hot sub-humid: 53.5% Hot humid: 41% Temperate humid: 3.5% Temperate: 1.5% Arid and semi-arid: 0.5% Very cold: 0.05%	Mean: 23 °C Maximum: 32 °C Minimum: 13 °C Precipitation: 1500 mm	Acrisol Fluvisol Humic andosol Hortic andosol Cambisol Phaeozem Mollic gleysol Lithosol Lixisol Luvisol Regosol Rendzic Vertisol
	Tabasco	Hot humid: 95.5% Hot sub-humid: 4.5%	Mean: 27 °C Maximum: 36 °C Minimum: 18.5 °C Precipitation: 2550 mm	Cambisol Fluvisol Gleysol Lithosol Arenic regosol

				Solonchak Vertisol
	Oaxaca	Hot sub-humid: 47% Hot humid: 22% Temperate humid: 16% Arid and semi-arid: 11% Temperate subhumid: 4%	Mean: 22 °C Maximum: 31 °C Minimum: 12.5 °C Precipitation: 1550 mm	Phaeozem Eutric fluvisol Hortic luvisol Luvisol Vertic luvisol Vertisol
South	Campeche	Hot sub-humid: 92% Hot humid: 7.75% Semi-arid: 0.05%	Mean: 26.5 °C Maximum: 30 °C Minimum: 18 °C Precipitation: 1700 mm	Salic gleysol Lithosol Eutric regosol
	Chiapas	Hot humid: 54% Hot sub-humid: 40% Temperate humid: 3% Temperate sub-humid: 3%	Mean: 23 °C Maximum: 30 °C Minimum: 17.5 °C Precipitation: 2600 mm	Acrisol Cambisol Luvisol Solonchak
	Quintana Roo	Hot subhumid: 99% Hot humid: 1%	Mean: 26 °C Maximum: 33 °C Minimum: 17 ° C Precipitation: 1300 mm	Gleysol Rendzic Vertisol

Sources: INEGI, 2012; CONADESUCA, 2009.

Table S5. The most important pests, predators and parasitoids for sugarcane cultivation in Mexico

Species	Order: Family	Common name in English (in Spanish)
On leaves		
Aeneolamia contigua Walker	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
A. contigua campecheana Fennah	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
A. contigua santa-rosae Fennah	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
A. albofasciata Walker	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
A. vilior Fowl.	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
A. postica Walker	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
A. postica occidentalis Fennah	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
Prosapia contigua Walker	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
P. bicinta Say.	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
P. bicinta angustata Walker	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
P. tepeana Fennah	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
P. simulans Walker	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
Zulia (*Neozulia vilior* Fowl.)	Hemiptera: Cercopidae	Spittle bug (Mosca pinta o salivazo)
Leptodictya tabida (Herrich-Schaeffer)	Hemiptera: Tingidae	Sugarcane lace-bug (Chinche de encaje)
Blissus leucopterus Say.	Hemiptera: Lygaeidae	Chinch bug (Chinche negra)
Saccharicoccus sacchari Cockerell	Hemiptera: Pseudococcidae	Pink sugarcane mealybug (Chinche rosada)
Saccharosydne saccharivora Westwood	Hemiptera: Delphacidae	Leafhopper (Saltahoja antillano)
Sipha flava Forbes	Hemiptera: Aphididae	Yellow sugarcane aphid (Pulgón amarillo)
Dysmicoccus boninsis Kuwana	Hemiptera: Pseudococcidae	Gray sugarcane mealybug (Chinche gris)

Mocis latipes Guenée	Lepidoptera: Noctuidae	Striped grassworm (Gusano medidor)
Trichoplusia ni Hübner	Lepidoptera: Noctuidae	Cabbage looper (Gusano falso medidor)
Cirphis latiuscula Herr. Sch.	Lepidoptera: Noctuidae	Army worms (Gusano soldado)
Spodoptera frugiperda J. E. Smith	Lepidoptera: Noctuidae	Fall armyworm (Gusano cogollero)
Elasmopalpus lignosellus Zeller	Lepidoptera: Pyralidae	Lesser cornstalk borer (Barrenador coralillo)
Schistocerca pallens Thunb	Orthoptera: Acrididae	Locust (Langosta)
S. paranensis Burmeister	Orthoptera: Acrididae	Locust (Langosta)
Chromacris colorata Serville	Orthoptera: Acrididae	Grasshopper (Chapulín)
Taeniopoda auricornis Walker	Orthoptera: Romaleidae	Grasshopper (Chapulín)
Tropinotus mexicanus Burmeister	Orthoptera: Romaleidae	Grasshopper (Chapulín)
On stems		
Diatrea considerata Heinrich	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
D. magnifactella Dyar	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
D. grandiosella Dyar	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
D. saccharalis Fabricius	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
D. veracruzana Box	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
D. lineolata Walker	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
D. muellerella Dyar & Heinrich	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
Eoreuma loftini Dyar	Lepidoptera: Crambidae	Sugarcane borer (Barrenador del tallo)
Cholus morio Champion	Coleoptera: Curculionidae	Sugarcane stalk weevil (Picudo del tallo)
On roots		
Phyllophaga crinalis Bates	Coleoptera: Scarabaeidae	Masked chafers (Gallina ciega o mayate)
P. sturmi Bates	Coleoptera: Scarabaeidae	Masked chafers (Gallina ciega o mayate)
Anomala cincta Say	Coleoptera: Scarabaeidae	Masked chafers (Gallina ciega o mayate)
Cyclocephala fulgurata Burmeister	Coleoptera: Scarabaeidae	Masked chafers (Gallina ciega o mayate)
Euetheola bidentata Burmeister	Coleoptera: Scarabaeidae	Sugarcane beetle (Mayatito de la caña)
E. humillis Burmeister	Coleoptera: Scarabaeidae	Sugarcane beetle (Mayatito de la caña)
E. rugiceps Le Conte	Coleoptera: Scarabaeidae	Sugarcane beetle (Mayatito de la caña)
Golofa pusilla Arrow	Coleoptera: Scarabaeidae	Rhinoceros beetles (Mayate rinoceronte)
Pyrophorus stella Candéze	Coleoptera: Elateridae	Wireworms (Gusanos de alambre)
Heterotermes tenuis Hagen	Isoptera: Heterotermitidae	Termite (Termitas)
Amitermes beaumonti Banks	Isoptera: Termitidae	Termite (Termitas)
Reticulitermes flavipes Kollar	Isoptera: Rhinotermitidae	Termite (Termitas)
Radopholus similis (Cobb) Thorne	Tylenchida: Pratylenchidae	Burrowing nematode (Nemátodo perforador)
Pratylenchus brachyurus Goldfrey.	Tylenchida: Pratylenchidae	Dagger nematode (Nemátodo daga)
Haplolaimus sp.	Tylenchida: Hoplolaimidae	Lance nematode (Nemátodo lanza)
Criconema sp.	Tylenchida: Criconematidae	Spine nematode (Nemátodo de la columna)
Sigmodon toltecus Saussure	Rodentia: Muridae	Rat (Rata cañera)
S. arizonae Mearns	Rodentia: Muridae	Rat (Rata cañera)
S. hispidus Say and Ord	Rodentia: Muridae	Hispid cotton rat (Rata algodonera)
S. mascotensis J. A. Allen	Rodentia: Muridae	Rat (Rata cañera)
Oryzomys couesi Alston	Rodentia: Muridae	Rat (Rata cañera)
Peromyscus leucopus Rafinesque	Rodentia: Muridae	Rat (Rata cañera)
P. maniculatus Wagner	Rodentia: Muridae	Rat (Rata cañera)
Handleyomys rostratus Merriam	Rodentia: Muridae	Rat (Rata cañera)
Rattus rattus Linnaeus	Rodentia: Muridae	Rat (Rata cañera)
Dipodomys phillipsii Gray	Rodentia: Heteromyidae	Rat (Rata cañera)

Liomys pictus Thomas	Rodentia: Heteromyidae	Rat (Rata cañera)
Orthogeomys hispidus Le Conte	Rodentia: Geomyidae	Pocket gopher (Tuza)
O. grandis Thomas	Rodentia: Geomyidae	Pocket gopher (Tuza)
Crathogeomys merriami merriami Thomas	Rodentia: Geomyidae	Pocket gopher (Tuza)
Predators		
Coleomegilla maculata De Geer	Coleoptera: Coccinellidae	Ladybird beetles (Catarina)
Castolus plagiaticollis Stol	Hemiptera: Reduviidae	Predatory bugs (Chinches predadoras)
Parasitoids		
Lixophaga diatraeae Townsend	Diptera: Tachinidae	Cuban fly (Mosca cubana)
Metagonistylum minense Townsend	Diptera: Tachinidae	Amazon fly (Mosca amazónica)
Paratheresia claripalpis Van der Wulp	Diptera: Tachinidae	Mexican fly (Mosca mexicana)
Palpozenillia palpalis Aldrich	Diptera: Tachinidae	Tachinid parasite of sugarcane (Mosca de Tepic)
Trichogramma pretiosum Riley	Hymenoptera: Trichogrammatidae	Egg parasitoid (Parásitos de los huevecillos)
T. minutum Riley	Hymenoptera: Trichogrammatidae	Egg parasitoid (Parásitos de los huevecillos)
Telenomus alecto Crawford	Hymenoptera: Scelionidae	Egg parasitoid (Parásitos de los huevecillos)
Iridomyrmex humilis Mayr	Hymenoptera: Formicidae	Argentine ant (Hormiga argentina)
Atta fervens Drury	Hymenoptera: Formicidae	Leafcutter ant (Hormiga defoliadora)

Sources: Flores (2007); Vásquez-López et al., 2013.

Table S6. Most common diseases for sugarcane cultivation in Mexico

Species	Type	Disease name in English (in Spanish)
Cercospora longipes E. J. Butler	Fungal	Brow spot (Peca o mancha café)
Leptosphaeria sacchari B. de Hann	Fungal	Ring spot (Mancha de anillo)
Bipolaris sacchari (E. J. Butler) Shoemaker	Fungal	Eye spot (Mancha de ojo)
Capnodium sp.	Fungal	Sooty mould (Fumagina de la hoja)
Anamorph: *Fusarium moniliforme* J. Sheld. *Gibberella subglutinans* (E. T. Edwards) P. E. Nelson, Toussoun & Marasas	Fungal	Pokkah-boeng (Cogollo retorcido)
Pythium spp.	Fungal	Pythium root rot (Pudrición del sistema radicular)
Ceratocystis paradoxa (Dade) C. Moreau	Fungal	Pineapple disease (Enfermedad de la piña)
Phaeocytostroma sacchari (Ellis & Everh.) B. Sutton	Fungal	Rind disease (Enfermedad de la corteza)
Marasmius sacchari Wakker *M. stenospilus* Montagne	Fungal	Marasmius basal stem, root and sheath rot (Pudrición de la base del tallo, de la raíz y de la vaina)
Cephalosporium sacchari E. J. Butler = *Fusarium sacchari* (E. J. Butler) W. Gams	Fungal	Wilt (Marchitez)
Cytospora sacchari E. J. Butler	Fungal	Sheath rot (Pudrición de la vaina)
Glomerella tucumanensis (Speg.) Arx & E. Müller = *Physalospora tucumanensis* Speg.	Fungal	Red rot (Pudrición roja del tallo)
Sporisorium scitamineum (Syd.) M.Piepenbr., M. Stoll & Oberw	Fungal	Smut (Carbón)
Puccinia melanocephala Syd. & P. Syd.	Fungal	Rust (Roya café)
P. kuehnii (W. Krüger) E.J. Butler	Fungal	Orange rust (Roya naranja)
Acidovoraz avanea Starr & Burkholder	Bacterial	Red stripe (Raya roja)

Leifsonia xyli subsp. *xyli* (Davis et al.) Evtushenko	Bacterial	Ratoon stunt (Raquitismo de las socas)
Xanthomonas albilineans (Ashby) Dowson.	Bacterial	Leaf scald (Escaldadura de la hoja)
Sugarcane mosaic virus (SCMV)	Virus	Mosaic (Mosaico de la caña)
Yellow leaf syndrome (YLS)	Virus	Yellow leaf (Hoja amarilla)

Sources: Chinea-Martín and Milanés-Ramos (2006); Flores (2007).

Table S7. Primary weed species for sugarcane cultivation in Mexico

Species	Family	Common name in English (in Spanish)
Annuals		
Thunbergia alata Bojer ex Sims	Acanthaceae	Blackeyed Susan vine (Ojo de pájaro)
Commelina diffusa Burm. f.	Commelinaceae	Climbing dayflower (Tripa de pollo)
Bidens pilosa L.	Asteraceae	Beggarticks (Acahuale blanco)
Melampodium divaricatum (L.C. Rich.) DC.	Asteraceae	Blackfoots (Botón de oro)
Parthenium hysterophorus L.	Asteraceae	Santa Maria feverfew (Escoba amarga)
Chamaesyce hirta (L.) Millsp.	Euphorbiaceae	Pillpod sandmat (Hierba de paloma)
Pharbitis purpurea (L.) Voigt	Convolvulaceae	Morning glory (Bejuquillo)
Digitaria ciliaris (Retz.) Koeler	Poaceae	Southern crabgrass (Zacate conejo)
Spermacoce assurgens Ruiz and Pav.	Rubiaceae	False buttonweed (Celestina azul)
Amaranthus viridis L.	Amaranthaceae	Green amaranth (Bledo verde)
A. hybridus L.	Amaranthaceae	Red amaranth (Quintonil)
Heliotropium indicum L.	Boraginaceae	Indian heliotrope (Molto)
Ageratum houstonianum P. Mill.	Asteraceae	Blue billygoat weed (Yerba del zopilote)
Euphorbia hyssopifolia L.	Euphorbiaceae	Hyssop spurge (Hierba de la golondrina)
E. dentata Michx.	Euphorbiaceae	Toothed spurge (Lechosilla)
Cenchrus echinatus L.	Poaceae	Burgrass (Zacate cadillo)
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	Itchgrass (Caminadora)
Senna obtusifolia (L.) H.S. Irwin & Barneby	Caesalpiniaceae	Java-bean (Palo zorrillo)
Phytolacca purpurascens A. Br. et Bouché	Phytolaccaceae	Pokeweeds (Chichán)
Brachiaria fasciculata B.	Poaceae	Signalgrass (Zacate de año)
Solanum nigrum L.	Solanaceae	Black nightshade (Hierba mora)
Conyza canadensis (L.) Cronquist	Asteraceae	Horseweed (Cola de caballo)
Tithonia spp.	Asteraceae	Mexican sunflower (Gigantón)
Momordica charantia L.	Cucurbitaceae	Bitter melon (Melón amargo)
Argemone mexicana L.	Papaveraceae	Mexican prickly-poppy (Cardosanto)
Plantago major L.	Plantaginaceae	Broadleaf plantain (Llantén mayor)
Portulaca oleracea L.	Portulacaceae	Purslane (Verdolaga)
Perennials		
Oxalis spp.	Oxalidaceae	Mexican oxalis (Trébol)
Borreria spp.	Rubiaceae	False buttonweed (Estrella blanca)
Mecardonia procumbens (Mill.) Small	Scrophulariaceae	Waterhyssop (Hierba té)
Verbena spp.	Verbenaceae	Vervain (Verbena)

Talinum paniculatum (Jacq.) Gaertn.	Portulacaceae	Big talinum (Rama de sapo)
Cenchrus echinatus L.	Poaceae	Southern sandspur (Zacate cadillo)
Paspalum distichum L.	Poaceae	Knotgrass (Camalote)
P. natatum Flüggé	Poaceae	Bahia grass (Zacate bahía)
Brachiaria mutica (Forssk.) Stapf	Poaceae	Signalgrass (Súrbana)
Cynodon dactylon (L.) Pers.	Poaceae	Bermuda grass (Zacate bermuda)
Sida spp.	Malvaceae	Fanpetals (Malva)
Mimosa pudica L.	Mimosaceae	Sensitive plant (Dormilona)
Sporobolus jacquemontii K.	Poaceae	American rat's tail grass (Zacate de mi casa)
Melinis repens (Willd.) Zizka	Poaceae	Rose natal grass (Pasto rosado)
Setaria macrostachya Kunth	Poaceae	Large-spike bristlegrass (Zacate cola de zorra)
Megathyrsus maximus (Jacq.) B.K. Simon and S. W. L. Jacobs (*Panicum maximum* Jacq.)	Poaceae	Guinea grass (Zacate privilegio)
Cynodon plectostachyus P.	Poaceae	Bermuda Grass (Pasto estrella)
Sorghum halepense (L.) Pers.	Poaceae	Johnson grass (Zacate Johnson)
Cyperus iria L.	Cyperaceae	Rice flatsedge (Coquillo paragüita)
C. rotundus L.	Cyperaceae	Nut grass (Coquillo rojo)
Ipomoea spp. (L.) Lam.	Convolvulaceae	Whitestar potato (Enredadera)

Sources: CNPR (2013); CONABIO (2012).

Table S8. Products registered by the National Service of Health, Food Safety and Quality (Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria, SENASICA) for the integrated management of weeds and pests of sugarcane in Mexico

Chemical Group	Common Name	Commercial Names
		Weeds
Growth regulators		
Phenoxycarboxilic acids	2,4-D	Agrester 400 CE, Esteron 47 M/Formula 40, Uniamina 720 CE, Herbipol 4-EB, Desmonte 4EB, Cuproester, Herbipol 334-E, Hierbester, 2,4-D Amina 72, Machetazo 2000, Novamina 480, Focus, Banvel 12-24, Crosser, Quron, Tordon 472-M, Diurpax, Resplandor 400
Benzoic acids	Dicamba	Fortune, 2-Camba, Herbamba, Banvel 12-24, Marvel
Pyridinecarboxilic acids	Picloram	Crosser, Quron, Tordon 472-M
Germination inhibitors		
Dinitroanilines	Pendimethalin	Prowl 400
Photosynthesis inhibitors		
Triazines	Atrazine	Gesaprim Calibre 90 GDA, Agrox 90 DF, Tetrimex 90 DF, Novaprin 501 FW, Atrapol, Atrazine 500, Desyerbal 500, Combi 80 PH, Caña Z, Atramet Combi 50 SC, Marvel
	Ametrine	Ametrex 80 WG, Gesapax Combi 80 PH, Ametrex 50 WP, Ametrina 500 FW, Novopax 501, Krismat 75 GS, Caña Z, Atramet Combi 50 SC, Diurpax, Resplandor 400, Sinerge 500 CE
Triazinones	Hexazinone	Hexapar 240 CE, Velpar K3, Advance
Triazolinones	Amicarbazone	Orion
Phenilureas	Diuron	Diurpax, Cention 800 FLO, Karmex 80 DF, Diurex 80 WG,

		Guerrero 800 DF, Advance, Velpar K3, Karmex Plus, Gramocil
Pigment synthesis inhibitors		
Isoxazolidinones	Clomazone	Gamit 480 CE, Command 480 CE, Sinerge 500 CE
Isoxazoles	Isoxaflutole	Provence 75 WG, Monte Limpio 75 WG, Merlin 75 WG
Inhibitors of amino-acid synthesis		
Sulfonilureas	Metsulfuron	Karmex Plus, Ally 60 WG, Escort
Imidazolinones	Imazapic	Plateau
Plasmatic membrane disintegrators		
Bipyridyls	Paraquat (restricted use)	Quemoxone, Helmquat, Herbipol, Gramoxone, Agroquat, Dragocson, Gramocil
Triazolinones	Carfentrazone	Affinity 240 CE, Focus
Organic arsenic	MSMA	Bueno 6, Daconate, Ansar 6, Target 720 SA, Gramopol
	Pests	
Targets nervous and muscular systems		
Carbamates	Carbofuran	Furadan 5G, Furadan 350 L, Mastin 5G, Convoy 5% G, Interfuran 3-G
	Aldicarb	Temik 15 G, Aldicine 15 G
Organophosphates	Clorpirifos	Magnum L-480, Clorpirifos 48% CE, Libero 480, Dinafos
	Terbufos	Counter FC-15% G
Neonicotinoids	Thiametoxam	Actara 25 GS
	Imidacloprid	Jade
Pyrethroids	Bifenthrin	Brigadier 0.3 G, Talstar 0.3 G, Capture 0.3 G, Hercules Ultra, Alstar 0.3 G
Organochlorates	Endosulfan	Thionex 350 EC, Mantis 350 CE, Endosulfan 350 CE, Endopol
Phenylpyrazols (Fiproles)	Fipronil	Regent 4 SC
Targets the digestive system		
Biological	*Bacillus thuringiensis*	Xentari GRD, Javelin WG, Dipel 2X, Thuricide PH, Agree, Delta BT, Aztron
	Beauveria bassiana	Naturalis L
Anticoagulant		
Coumarins	Difethialone	Rodilon, Solvirex 15%, Disyston 10 GR

Source: SENASICA (2011).

Table S9. Industrial groups and independent refineries involved in the processing of sugarcane primary material in Mexico and productivity level per refinery operating during the 2012/2013 harvest

Industrial Group	Refinery	State	Productivity Level
Agazucar S.A. de C.V.	Puga	Nayarit	Medium
SAGARPA-FEESA (Federal Government)	Atencingo	Puebla	Very high
	Casasano (La Abeja)	Morelos	Very high
	El Modelo	Veracruz	High
	El Potrero	Veracruz	Medium
	Emiliano Zapata	Morelos	Very high
	La Providencia	Veracruz	Medium
	Plan de San Luis	San Luis Potosí	Very low
	San Cristóbal	Veracruz	Low
	San Miguelito	Veracruz	High
Grupo Azucarero del Trópico S.A. de C.V.	La Gloria	Veracruz	High
	La Joya	Campeche	Very low
Grupo Azucarero México S.A. de C.V.	El Dorado	Sinaloa	High
	José María Martínez (Tala)	Jalisco	High
	Lázaro Cárdenas	Michoacán	High
	Presidente Benito Juárez	Tabasco	Very low
Grupo Beta San Miguel	Constancia	Veracruz	Medium
	Quesería	Colima	High
	San Francisco Ameca	Jalisco	High
	San Miguel del Naranjo	San Luis Potosí	Low
	San Rafael de Pucté	Quintana Roo	Very low
	Santa Rosalia (La Chontalpa)	Tabasco	Very low
Grupo García González	Calípam	Puebla	High
	El Carmen	Veracruz	Medium
	Nuevo San Francisco	Veracruz	Very low
Grupo La Margarita	Central Progreso	Veracruz	Low
	José María Morelos	Jalisco	Medium
	La Margarita	Oaxaca	Medium
Grupo Motzorongo	Central Motzorongo	Veracruz	Medium
	El Refugio (Santa Isabel)	Oaxaca	Medium
Grupo Pantaleón	Pánuco	Veracruz	High
Grupo Porres	Huixtla	Chiapas	High
	San Pedro	Veracruz	Low
	Santa Clara	Michoacán	High
Grupo Promotora Industrial Azucarera S.A. de C.V. (PIASA)	Adolfo López Mateos	Oaxaca	Medium
	Tres Valles	Veracruz	Low
Grupo Sáenz	Aarón Sáenz Garza	Tamaulipas	High
	El Mante	Tamaulipas	Medium
	Tamazula	Jalisco	Very high
Ingenios Santos S.A. de C.V.	Alianza Popular	San Luis Potosí	Very low
	Bellavista	Jalisco	Medium
	Cuatotolapan	Veracruz	Low

	Pedernales	Michoacán	High
	Plan de Ayala	San Luis Potosí	Very low
	San Gabriel	Veracruz	Low
Zucarmex	Cía. Azucarera La Fe (Pujiltic)	Chiapas	High
	El Higo	Veracruz	High
	Mahuixtlán	Veracruz	High
	Melchor Ocampo	Jalisco	Very high
Independientes	Avance Regional (La Primavera)	Sinaloa	High
	Azuremex (Tenosique)	Tabasco	Very low
	El Molino	Nayarit	Medium
	Los Mochis	Sinaloa	High
	San José de Abajo	Veracruz	Low
	San Nicolás	Veracruz	Medium

Sources: MAM (2013); Aguilar-Rivera et al. (2012).

Table S10. Selection process for sugarcane varieties in Mexico

Phase	Evaluation period		Selection pressure	Estimated number to plant	Nomenclature	Experimental plot	Total area (ha)	Location	Activity
	Cycle	Months							
Seedling	2nd harvest	18	20%	30 000	Hybrids	1 variety every m	4.5	Experimental field	Applied investigation
Row	2nd harvest	24	20%	6000	Varieties	1 row of 3 m	4.5	Experimental field	Applied investigation
Stump	2nd harvest	24	20%	6000	Varieties	1 stump every 1.8 m	4.5	Experimental field	Applied investigation
Parcel	2nd harvest	24	20%	1200	Varieties	3 rows of 5 m	5	Experimental field	Applied investigation
Multiplication I	Planting	10-12	---	240	Varieties	4 rows of 5 m	1.2	Experimental field	Applied investigation
Adaptability test	2nd harvest	24	20%	240	Varieties	3 rows of 10 m	2	Experimental field	Applied investigation
Multiplication II	Planting	10-12	---	48	Varieties	5 rows of 25 m	1.2	Experimental field	Applied investigation
Agroindustrial evaluation	>2nd harvest	38-42	20%	48	Varieties	6 rows of 12 m	1	Experimental field	Applied investigation
Multiplication III	Planting	10-12	---	1-10	Promising varieties	15 rows of 50 m	1.2-12	Experimental or commercial field	Applied investigation
Semicommercial test	Planting	10-12	---	1-10	Prospective commercial varieties	1 ha	1-10	Commercial field	Experimental development
Nursery seedbed	Planting	10-12	---	1-10	Available varieties	10 ha	10-100	Commercial field	Development

Source: IMPA (1983).