TECNOCIENCIA CHIHUAHUA
Revista de ciencia y tecnología

ISSN-e: 2683-3360

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UNIVERSIDAD AUTÓNOMA DE CHIHUAHUA

Artículo de Divulgación

The paradoxical availability of raw materials in the bioethanol production

La paradójica disponibilidad de materia prima en la producción de bioetanol

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DOI: https://doi.org/10.54167/tch.v17i3.1225
Recibido:: 04 de junio de 2023; **Aceptado**: 05 de octubre de 2023
Publicado por la Universidad Autónoma de Chihuahua, a través de la Dirección de Investigación y Posgrado

Abstract

The production of bioethanol is influenced by economic, social, political, and technological aspects. Technology has contributed to improving and simplifying the production process. On the other hand, the global pandemic of SARS-CoV-2, better known as Covid-19, has affected the market as its price has substantially increased. Raw material and transportation costs have also impacted the international market. Therefore, more efforts are being dedicated to finding alternative raw materials for bioethanol production. Agricultural waste or starches that are not used entirely for human consumption have the potential to produce bioethanol, but paradoxically, they cannot be commercialized. This report focuses on potential raw materials for bioethanol production and how their possible commercial exploitation declines when they acquire a cost for their transformation into higher value-added products. Price increases discourage investment in the diversification of these raw materials

Keywords: **bioethanol, cellulose, corn, fermentation, lignocellulose, starch.**

Resumen

La producción de bioetanol está influenciada por aspectos económicos, sociales, políticos y tecnológicos. La tecnología ha contribuido a mejorar y simplificar el proceso de producción. Por otro lado, la pandemia mundial del SARS-CoV-2, más conocido como Covid 19, ha afectado al mercado ya que su precio ha aumentado sustancialmente. Los costos de materia prima y transporte también han impactado el mercado internacional. Por lo tanto, se dedican más esfuerzos a encontrar materias primas alternativas para producir bioetanol. Los residuos agrícolas o los almidones que no son totalmente utilizados para el consumo humano tienen potencial para producir bioetanol, pero, paradójicamente, no pueden comercializarse. Este reporte se enfoca sobre materias primas potenciales para producir bioetanol y cómo decae su posible explotación comercial cuando adquieren un coste por su transformación a productos de mayor valor agregado. Los aumentos de precios desalientan la inversión en la diversificación de estas materias primas.

Palabras clave: **bioetanol, celulosa, maíz, fermentación, lignocelulosa, almidón.**

1. Introduction

The ethanol industry is a robust industry that has been developed over many decades. Samuel Morey developed in 1825 a prototype of an internal combustion engine that ran on ethanol and turpentine (Morey, 1926). The growth of the ethanol industry was rapid, and its boom increased suddenly in 2006 when the president of the United States of America (USA), George W. Bush, delivered his State of the Union Address, in which he said very clearly, "We must also change how we power our automobiles. We will increase our research on better batteries for hybrid and electric cars and on pollution-free cars that run on hydrogen. We'll also fund additional research in cutting-edge methods of producing ethanol, not just from corn but from wood chips, stalks, or switchgrass. Our goal is to make this new kind of ethanol practical and competitive within six years" (Bush, 2006). This statement was based on the issue that the USA depends too much on foreign oil, specifically countries in conflict, which is affecting its national energy security. It cannot necessarily be interpreted that fossil fuels would end and could be partially replaced by ethanol.

This led to the emergence of certain economic aspects; for example, the price of corn increased as a result of the political mandate regarding the encouragement of the use of ethanol as fuel (Griffin & Ariz, 2007). At the same time, many scientific reports begin with the argument that "The growth of the world population is causing major problems, some of them related to the depletion of energy sources" (Bhatia *et al*. 2012; Soltanian *et al.* 2020; Robak & Balcerek 2020). It is also reported that "fossil fuels derived from petroleum are raw materials that are being depleted throughout the world due to their overexploitation, causing an increase in their costs and byproducts" (Kasibhatta, 2020). This phenomenon has promoted the development of sustainable, cost-effective, and environmentally friendly energy sources such as biofuels (bioethanol, biodiesel, and biogas). In the case of the USA, the federal government provides a series of subsidies to increase the consumption of biofuels specially derived from corn ethanol (DOE, 2023). The subsidies include tax breaks, donations, loans, and loan guarantees. The government also imposed a mandate to blend biofuels with gasoline and diesel fuel. Supporters of biofuels argued that these policies lower gas prices, strengthen the economy, and benefit the environment, but none of those statements proved to be true (Loris, 2017).

It is important to clarify that this manuscript does not aim to provide an overview of the current state of the ethanol industry in terms of process economics and raw material usage. Numerous papers have already covered these aspects in detail, making it unnecessary to delve into them here (Mizik, 2021; Danelon *et al.,* 2023; Gutierrez *et al.,* 2023; Nimbalkar *et al*., 2023; Onu Olughu *et al.,* 2023; Sica *et al*., 2023). Instead, the following section focuses on illustrating cases where the cost of a raw material transitions from being affordable to expensive when pursued for industrial applications, such as ethanol production. This shift occurs due to various factors, including not only the availability of raw materials but also the opportunities that arise for their commercial exploitation.

Therefore, this report highlights the untapped potential of abundant materials for ethanol production, despite facing economic challenges. It begins by examining starch, which is categorized as a first-generation (1G) raw material. Section 2.1 specifically discusses a unique case that occurred in Malaysia in 2006.

2. Availability of raw materials for ethanol production

It is evident that each country must adjust its necessities to its geographical situation to have the agricultural products that are most favorable for producing ethanol. Thus, for example, it is well known that the USA uses mainly corn; Brazil uses sugar cane; European countries generally use sugar beets; and some Asian countries, for example, Thailand, use potatoes, while Malaysia intends to use sago starch (Chua *et al*., 2021). Many governments have a direct influence on the actions required to motivate technology development for the promotion of specific crops. For example, in the USA, the Biofuel Systems Division of the Department of Energy (DOE) sponsors and supports the Biomass Ethanol Program. In 2019, the DOE announced more than $ 79 million in funding for bioenergy research and development, including biofuels and bioproducts. With this type of subsidy, in addition to financing from the private sector, the cost of biomass-derived ethanol is expected to drop considerably.

In Mexico, there is the Law for the Promotion and Development of Bioenergy. This law promoted the creation of the Bioenergy Commission, which is integrated by different sectors such as the Ministry of Agriculture, Livestock, Rural Development, Fisheries, and Food (SAGARPA), the Ministry of Energy (SENER), the Secretariat of the Environment and Natural Resources (SEMARNAT), the Ministry of Economy (SE), and the Ministry of Finance and Public Credit (SHCP). These institutions have a broad power to establish the national strategy for the promotion and development of biofuels, a task that requires listening to the opinion of the Inter-ministerial Commission for Sustainable Rural Development in relation to the production and marketing of supplies (Becerra-Pérez, 2009).

2.1. Production of starch-based ethanol

This section aims to explain how the availability of raw materials and their costs impact a production process, or at least an intention to produce value-added products. It is a case that explains the use, handling, and conversion of sago starch to ethanol. Malaysia is a country with a starch production of approximately 54,000 tons per year from a palm tree called "Sago" (Fig. 1).

Source: Property of the authors

Figure 1. Sago palm trees
Figura 1. Palmeras sago

"In this figure, you can see the palm tree trunks. These trunks are cut to a length of 4 feet, regardless of their diameter. This practice is necessary because the transportation vehicles cannot access the dense jungle, so the trunks are instead transported by floating them down the river to the processing mills. As indicated in Table 1, it takes approximately 6.86 trunks to make up one ton, with each trunk incurring a cost of USD $ 18. Comprehensive plant studies have been reported covering all aspects of agricultural science (Flach, 1997; SSPS, 2015; Ehara *et al.,* 2018). Also stimulated by the 2006 ethanol boom, the University Malaysia Sarawak (UNIMAS) and the Japanese company New Century Fermentation Research Co. Ltd. (Necfer) signed a technology transfer agreement. Necfer would generate the technology, UNIMAS would act as a technical advisor, and the project was awarded to the company AARGYP Scientific Sdn. Bhd. (AGS) (Engormix, 2008). The Malaysian Ministry of Science, Technology, and Innovation (MOSTI) was the provider of research funding. The contract stipulated that the Malaysian government would be the owner of the technology for industrial exploitation, and Necfer would collect royalties for being the intellectual owner of the technology.

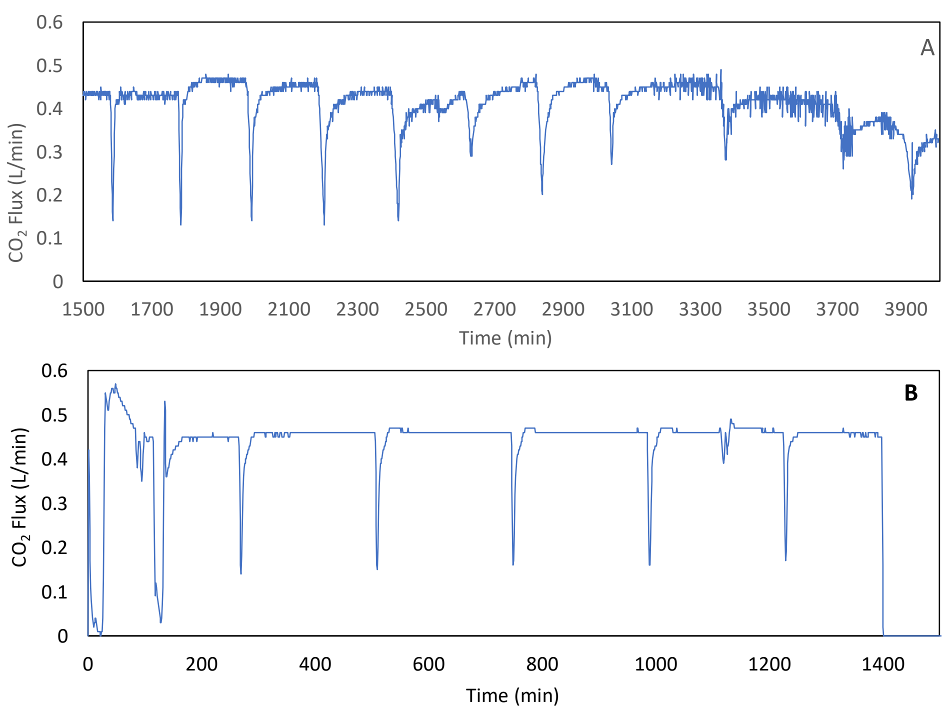
The economic analysis without including operating expenses that predicted success for the installation of a pilot plant with a capacity of 2000 L/day is presented in Table 1. The pilot plant consisted mainly of three processes identified as sago starch hydrolysis, fermentation, and ethanol purification. Sago starch is hydrolyzed using an α-amylase enzyme to liquefy it to produce dextrin. The process also showed advantages because the electricity and the steam could be generated by the concept of cogeneration (Cog.), as shown in Table 1. Subsequently, the α-gluco-amylase enzyme is used for the saccharification process to produce glucose of high concentration, ready to be used in the fermentation process. Necfer signed the technology transfer agreement for ethanol production in continuous culture, which claimed to be the most efficient process in the world with an effective cost of $ 148.0 per ton of ethanol produced. The technology was promising, as it was a fast and compact process. The fermentation tanks were small in capacity compared to tanks that should be used in a batch process. As it is known, one way to improve the processes is to seek better technologies and control of operating parameters.

Table 1. Estimated cost of ethanol production using Sago palms
Tabla 1. Costo estimado de la producción de etanol a partir de la palma sagú

Product	Unit	Amount per ton	Unit Price (USD)	USD / ton
Sago palm	Trunk	6.89	18.00	124.04
α -Amylase	L	0.86	11.00	9.80
Glucoamylase	L	0.86	11.00	9.80
PGK (106 U/g)	g	6.20	0.03	0.18
PGK (106 U/g)	g	6.20	0.03	0.18
Defoamer	L	1.00	1.00	1.0
Electricity	KWH	--	--	Cog.
Steam	Ton	3.00	--	Cog.
Water	m^3	15.0	0.20	3.0
Waste treatment	m^3	15.0	--	Irrigation
Estimated cost				148.0

Data from Necfer Corporation LTD and Herdsen Sago Chemicals, Pusa, Sarawak.

This section shows how better control of operating parameters results in a product with better quality and higher substrate conversion efficiency. However, this improvement did not affect the production cost significantly. It does not matter how much the technology is improved; the profit cannot compensate the increase in the raw material price. Fig. 2A shows the kinetics of ethanol fermentation in the original process before improving the technology.



Source: Property of the authors

Figure 2. Kinetics of CO_2 produced during the ethanol fermentation. A). Original technology for monitoring the flow of CO_2. B) Improved technology for controlling and measuring the flow of CO_2.

Figura 2. Cinética del CO_2 producido durante la fermentación del etanol. A). Tecnología original para controlar el flujo de CO_2. B) Tecnología mejorada para controlar y medir el flujo de CO_2.

The CO_2 that is released during glucose metabolism is measured by a mass flow meter (Digital Mass Flow Controller DF-200C series, Kyoto, Japan) and real time graphing. As can be observed the blue curve reflects an undesirable variation in the CO_2 flux. Another observation is that downward lines happen because substrate feed is cut off. As fermentation is very fast, before the CO_2 drop reaches zero, the substrate flow is restored. When feeding substrate again, the metabolism is re-established, but there is a greater effort of the microorganisms to get a steady state which is why it is observed that the CO_2 line is curved with high fluctuations, which causes the yeast to decrease its productivity.

The problem was to solve the metabolic phenomenon by finding the conditions for the variation of CO_2 to be at the minimum level. Fig. 2B shows the CO_2 flow after improving the technology. The ethanol production was 35 g/L.h at an average concentration of 8 %. The process is continuous and is one of the fastest compared to those reported in the literature, taking the precaution of saying that it is a private property of the company and not publishable. The microorganism used was *Saccharomyces cerevisiae* CSI-1 (JCM 15097). All points favored the transfer of technology.

A press conference was held where the first sago-based ethanol production plant was announced (Fig. 3), in addition to being announced in other media (Engormix, 2008). At the same time, the company SP Chemicals Holdings Ltd. from Singapore invested capital to modify the starch production process from a wet to a dry process. The technology was successful because it is obvious that reducing the use of water in a process brings many benefits, such as avoiding costly wastewater treatment. It happened that when trying to do tests on a pilot scale, a purchase and sale agreement for sago palms was not reached between the company and the producers, which led to failure and total losses. Here, the economic factor plays a very important role when it comes to moving raw materials from one country to another. Malaysia produces sago starch and sells it to countries such as Japan and Singapore. The situation is that Malaysia has the control of the sago starch-based production plants. As a result of releasing news about the industrialization of sago starch, the market was quickly affected, and when the pilot plant was under construction, the market price of starch rose from $ 200 to $ 500 per ton in 2010 and reached $ 700 without transportation charges in 2018, which was 35 % and 20 % more expensive than cassava and corn starches, respectively (Jong, 2018). Calculations with the adjusted price, in addition to inputs, indicated that it was no longer affordable to produce ethanol using sago starch as a raw material. The price of producing ethanol with sago starch increased to $ 823 when the cost of ethanol in the international market was only $ 500. Investors withdrew, and the project failed completely.

The pilot plant in Malaysia was completed and could only be tested once because there was no interest from companies using glucose and ethanol. A little more research could be done to turn the plant into the one that produces lactic acid for the food, chemical and pharmaceutical industries. In this case, the cost of lactic acid is higher than that of ethanol used for fuel because the purity requirements are more demanding. Market pressure had a huge influence on the commercialization of sago when it was learned that sago would eventually acquire additional value as a diversified product. In the end, Malaysia is just an exporter of sago starch, which is a disadvantage for the country because it could turn sago starch into higher value-added products such as maltodextrins, glucose, flour products, and fermentation products.

» Home 8 • EASTERN TIMES » TUESDAY JANUARY 13, 2009

Prof. Dr Khairuddin Ab Hamid (2nd right), exchanging documents with Goh Yau Ping (2nd left) after signing of the MoU witnessed by Dr Cirilo Nolaso Hipolito (left), Prof. Dr Peter Songan (right) and Prof. Dr Kopli Bujang. PHOTO: RAMIDI SUBARI

Sago can be turned into fuel: UNIMAS

By Wilfred Pilo & Anasathia Jenis

KUCHING: Sago biomass either in form of starch or waste can be turned into ethanol for fuel through a process, according to UNIMAS Vice chancellor, Professor Dr Khairuddin Ab. Hamid.

He revealed this in his speech before he signed a Memorandum of Agreement on behalf of University Malaysia Sarawak (UNIMAS) with AARGYP Scientific Sdn Bhd (AGS) yesterday .

Dr Khairuddin said the fermentation process has 99.3% recovery, producing over 1000 litres of ethanol from about 1 ton of sugar equivalent. The focus is not so much on using sago starch, but more on utilisation of sago waste which will help reduce the pollution of the environment by local sago industries.

He added that sago solids can be economically treated using enzymes into fermentable sugars and consequently into ethanol. Sago effluent, the liquid by-product from the separation of fibers from sago wastewater has been modified, studies and utilized in Unimas for cultures of the alga Spirulina as food supplement, with possible production of biodiesel using selected petro-algae.

Dr Khairuddin said although some highly technical components will have to be purchased from suppliers abroad, the basic structures and components of the pilot plant would be constructed using the skills of local engineers and contractors, as recognised and selected by AGS.

He said a vacant plot has been identified in UNIMAS for the pilot plant, and construction will commence soon. The pilot-plant would come complete with down-stream processing unit and water treatment facilities is projected to be fully operational by the end of this year.

The project aims to produce ethanol as an additive at 18% or E18 to fossil fuel for automobiles, which has been adapted in the future plans by the US, most of the European, Japan and neighbouring countries such as Singapore, Philipines and Thailand.

As for AARGYP Scientific Sdn Bhd (AGS), he disclosed it as an industrial partner in the construction of a full-scale pilot plant (1000L or 1 ton/day) for the production of ethanol for fuel from sago biomass. He said that the construction cost would be fully funded through Techno-Fund, a research grant awarded by the Minister of Science, Technology and Inovation (MOSTI) to AGS in August 2007.

He pointed out that Techno-Fund is a pre-commercialisation grant which undertake innovation to develop and commercialise new, cutting edge and breakthrough technologies and aims to stimulate the growth and successful innovation, together with enhancing global competitiveness and R&D among Malaysia medium and large enterprises.

He disclosed that the signing of the MOA yesterday was an achievement accumulated over several years of research in utilisation of sago starch, sago effluent and biomass by Prof. Dr Kopli Bujang of UNIMAS, and Prof. Emeritus Dr Ayaaki Ishizaki of New Century Fermentation Research (NECFER) of Kurume, Japan, a research partner with UNIMAS in the venture.

He added that an MOU was signed earlier on August 4, 2006 between UNIMAS and NECFER to enhance research in the specific field of biofuel from sago.

This project was presented earlier by UNIMAS together with NECFER to the Chief Minister of Sarawak in 2007 .

He later signed on behalf of UNIMAS and AGS was represented by the Chief Executive Officer, Goh Yau Ping.

The signing was witnessed by Dr Cirilo NolascoHi[olito, the General Manager of New Century Fermentatation Research (NECFER) of Kurune, Japan, a research partner with UNIMAS in this venture.

Figure 3. Press conference announcing the premiere bioethanol production from sago starch.
Figura 3. Rueda de prensa para anunciar el estreno de la producción de bioetanol a partir de almidón de sagú.

2.2. Availability of sugarcane to produce ethanol

There is no doubt that the most widely available and abundant raw material in Mexico is sugarcane (CONADESUCA, 2021). Sugarcane is used to produce sucrose as a multipurpose sweetener. The process generates molasses as a by-product, which still contains a residual amount of fermentable sugars. The cost of sugar cane per ton was USD $ 40.2 in 2019 and USD $ 45.6 in 2020 (CONADESUCA, 2020), which was quite satisfactory for farmers. Few mills produce ethanol directly from sugarcane juice since they have their own distillery; however, they can use either juice or molasses. Other companies are independent and produce ethanol only from molasses. Molasses production during the 2015-2016 harvest was 1,975,715 tons at a cost of USD $ 174.3 per ton (CONADESUCA, 2016). During the authors' visit to the distillery of La Gloria sugar mill in the state of Veracruz, it was reported that when the cost of molasses increases to close to $ 200, the plant stops producing ethanol and molasses is sold as raw material for animal feed.

On the other hand, the Ministry of Economy reported that for the October 2019 to September 2020 cycle, the USA imported up to 1.65 million metric tons of Mexican sugar, the highest quantity since 2014 (SECOM, 2020). Carlos Blackaller Ayala, President of the National Sugarcane Farmers Union, considered that despite the drought in 2021, there was the availability of molasses (a by-product of sugar extraction), which is the raw material to make ethanol (Gómez-Mena, 2020). However, the demand has increased dramatically given that ethanol has been diverted to be used as an additive in the preparation of sanitary gels in stopping the spread of the viral infection by Covid-19 (PMFarma, 2020).

Therefore, ethanol use may be diverted from biofuel production towards different priorities. Ethanol could find a free path when there is a surplus in sugarcane production (Becerra-Pérez, 2009). Although there is bioethanol fuel on the market, it has not spread to the entire Mexican territory. Fig. 4 shows a map of the distribution of ethanol fuel (also known as oxyfuel) stations produced by the company Grupo Báltico.

In Fig. 4, it can be observed that the presence of oxyfuel stations corresponds to the areas where mainly sugar cane is grown and near consumer markets close to transportation routes; although it is recommended that oxyfuel only be used in vehicles equipped with oxyfuel combustion technology. The behavior of the market for ethanol is volatile and sensitive to factors such as variations in the cost of oil, the effects of climate and agriculture issues on the availability of raw materials, and most recently, the effects of the Covid-19 pandemic was very significative regarding the economics of the process. The ethanol industry is under recovery path.

A situation arises where gasoline prices fell or at least remained stable, but on the contrary, ethanol stopped being competitive because it rose to never-before-seen prices of up to 51.0 pesos MX per liter or even more due to high demand (Martínez-Riojas, 2020). During the pandemic, it was difficult to use ethanol as a biofuel because companies that produce it obtained a much greater economic benefit by diverting production to the pharmaceutical industry.

Figure 4. Oxyfuel stations in Mexico (Fuente google maps)
Figura 4. Estaciones de oxicombustión en México (Fuente google maps)

It is very certain that the global demand for ethanol for use in the pharmaceutical industry does not exceed the demand for consumption as biofuel, which is true, but that effect is negligible if the new price of ethanol is considered. In the words of the markets, it does not matter who demands more but rather who pays the best. Given the current situation in Mexico with raw materials, the most viable option to produce biofuels is sugar cane. Now that the pandemic situation has been mitigated the price of ethanol drops again to less than USD $ 1 per liter to be considered once again as a fuel additive to gasoline. However, Senator Raúl Bolaños Cacho emphasized in his report to the Senate of the Republic regarding his participation in the 2022 National Ethanol Conference held in New Orleans, USA, that in Mexico, there are reservations about the use of ethanol as a fuel. The senator points out that this is because there is not widespread confidence in ethanol as a biofuel. Firstly, because the ethanol-gasoline blend is not suitable for all vehicles, and secondly, because there is no technical or scientific evidence to ensure the reliability of its use for public health or the environment (Bolaños-Camacho, 2022).

2.3. Ethanol production from corn

In the case of corn and Mexico, this discussion ends very soon because in Mexico there is very little opportunity to produce ethanol from corn (ZafraNet, 2011). There are two main reasons: white corn is designated for human consumption and yellow corn is designated for animal feed. In another aspect, corn harvest per hectare is very low, being around 3-4 tons; this last factor takes away economic competitiveness. More worrisome is that Mexico, being the sixth largest producer of corn in the world, is the first importer of corn in the world (GCMA, 2020). This is simply a consequence of the fact that Mexico is a country with a corn culture. Then, economically it is not feasible to produce ethanol from corn in Mexico. Contrary to this, most of the world's corn-based ethanol production is performed in the United States.

There is a scientific controversy in the study of input and output energy balance in ethanol production. For many years, the group of scientists led by David Pimentel has argued that the production of biofuels, especially ethanol, is not feasible from an energy and economic point of view (Pimentel, 2003, 2009). However, an opposing view generated in 2002 and updated in 2004 says verbatim, "The debate is over: ethanol is a net energy winner" (Wang & Santini, 2002). This report was written in cooperation with the United States Department of Agriculture, which confirmed that the production of fuel-grade ethanol produces significantly more energy than that used in its production, with the clarification that the other by-products must be considered (Durante & Sneller, 2009), but this assertion refers exclusively to ethanol production using corn. Supporting this argument is that ethanol has been shown to reduce greenhouse gas emissions when compared with conventional gasoline (Scully *et al*., 2021). A concentration of 10 % corn-derived ethanol blends provided a 20 % CO_2 reduction, while biomass-derived ethanol could result in a nearly 100 % CO_2 reduction.

Ethanol is the cheapest way to increase octane in gasoline (Gaspar, 2019) because it contains oxygen, which contributes to the combustion process; this causes gasoline to burn more completely (Ciolkosz, 2014). Another important argument for why the ethanol industry has been considered feasible is made by considering the by-products obtained from the processing of corn (DOA, 2020). These by-products are considered to balance the energy balance, so they help to conclude that ethanol production is a thermodynamically favorable process. The most important of these by-products are: condensed distillers soluble, corn distillers oil, dried distillers grains, distillers dried grains with solubles, distillers wet grains, 65 % or more moisture. modified distillers wet grains, 40 to 64 % moisture.

In the US, corn farmers have incentives and have improved their cultivation techniques. Distillers also have incentives for their installed production capacity. Corn production in the US is between 10 and 12 tons per hectare (Becerra-Pérez, 2009), which is much higher than in most corn-producing countries. In the case of Mexico, for several years the country has ceased to be self-sufficient in corn production, and there is a need to import from the United States and Brazil (Moreno-Sáenz *et al*., 2016). Table 2 shows the states with the most corn production, although it is not enough to satisfy national demand, which is why it is dismissed as a raw material to produce ethanol (SIAP, 2020).

Table 2. Corn grain production spring-summer cycle 2018 vs 2019*P/ 2020 (thousands of tons)
Table 2. Producción de maíz en grano ciclo primavera-verano 2018 vs 2019*P/ 2020 (miles de toneladas)

	2018	2019	Annual (%) Variation	(%) Participation (2019)
National	18,881	17,911	-17.50	100.0
Jalisco	3,584	3,519	-22.21	14.17
Michoacán	1,952	1,907	-19.24	9.42
México	1,926	1,826	8.48	9.21
Guanajuato	1,694	1,703	20.65	8.55
Chihuahua	1,477	1,415	-20.87	8.16
Rest	8,248	7,541	-22.85	50.49

Source: (SIAP, 2020)(*Preliminary data of the 2020 report).

2.4. Production of ethanol from lignocellulosic materials

For decades, it has been argued that lignocellulosic biomass are the most abundant materials on the planet. While this is true, the problem that has been studied most is obtaining the energy that is stored in them. Here we report on the case of sugarcane bagasse and sweet sorghum in a context to understand how this matter can have another purpose, not necessarily that of producing ethanol. Nowadays, many mills are changing their energy consumption systems and are opting for the concept called cogeneration, although this concept is not new because several sugar mills have used bagasse as fuel for boilers to generate energy (Bhutani *et al*., 2020; Kamate & Gangavati, 2009). This situation means that the availability of bagasse decreases its priority to be converted to ethanol. Research done to produce ethanol from bagasse has a detractor in its original conception, that is, obtaining energy from agricultural residues. For example, the Adolfo López-Mateos Sugar Mill in the city of Tuxtepec, Oaxaca, received an investment of 60 million dollars in 2016 to implement cogeneration technology (Flores, 2016). The plant was inaugurated on February 27th., 2018. This means that currently, this mill produces its own energy by burning bagasse and therefore saves a great deal on the purchase of fuel that they have been using for decades. To carry out the cogeneration process, bagasse is burned in a 250 Ton/h steam boiler and generates around 40 megawatts of energy, the same as the Tres Valles Sugar Mill in the Veracruz state, which also generates 40 megawatts of energy. It is evident that important changes are taking place in the way of looking at lignocellulosic residues. The idea of producing bioethanol is moving away from these companies, or at least the availability of the supposed raw material at zero cost or minimum cost has diminished.

In the case of sweet sorghum, information and experience in Mexico are scarce. The main obstacles to the development of 2G biofuels are the high production costs in the pretreatment stage, the high cost of the enzymes used to hydrolyze the lignocellulosic material, and the difficulty of converting 5-carbon sugars into ethanol. To achieve this purpose, it is necessary to apply a lot of energy to try to break the structure of these materials. Despite the complications of producing 2G ethanol, this technology is being studied by a group of researchers, for instance, the group from the Technological Institute of Veracruz. This group has succeeded in scaling up an ethanol production process using sweet sorghum bagasse. The process has been successful in its demonstration stage and is awaiting investors who might bet on the development of this technology. The challenge is that sweet sorghum is not cultivated at the same rate as sugarcane. Therefore, great efforts are necessary to encourage the farmers to change their agricultural practices to sweet sorghum.

Conclusion and perspectives

The ethanol industry is a robust and well-established market. The feasibility of ethanol production relies heavily on the cost and availability of raw materials. Among the available options, sugarcane stands out as the most feasible material due to its high production volume and existing infrastructure. While sweet sorghum juice shows promise, its cultivation needs to be actively encouraged. Moreover, lignocellulosic materials such as corn stubble, sugarcane bagasse, and sweet sorghum bagasse have the potential to serve as raw materials for producing fermentable sugars. To ensure the availability of these biomass sources, effective management systems must be implemented in collaboration with farmers. While cane molasses can still be considered as a viable raw material source, cane juice is preferred for ethanol production as it facilitates easier treatment of effluents. Paradoxically, the abundance of raw materials becomes a hurdle when industrial exploitation becomes feasible, resulting in increased raw material prices. Therefore, making the ethanol production process economically viable requires not only the implementation of advanced technologies to enhance efficiency and productivity but also an increase in the yield of raw materials per hectare of land cultivation.

Conflict of interest

The authors confirm that they do not have any type of economic advantage or private relationship that could interfere or prevent the publication of this work.

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