Letters in High Energy Physics
ISSN: 2632-2714 Volume 2024

Historical Evolution and Sustainable Transformation of the Sugar Industry in the Cauca Valley (Colombia): Four Centuries of Innovation and Challenges

[1]Gonzalez-Ramirez Luisa Fernanda, [2]Rodríguez-Miranda Juan Pablo, [3]Rodríguez-Díaz Yim James

[1]Profesor Asociada. Universidad Distrital Francisco Jose de Caldas, Bogotá, Colombia. . Correo electrónico: lfgonzalezr@udistrital.edu.co
ORCID: https://orcid.org/0000-0001-8489-6761
[2]Profesor Titular. Universidad Distrital Francisco Jose de Caldas, Bogotá, Colombia. . Correo electrónico: jprodriguezm@udistrital.edu.co
ORCID: https://orcid.org/0000-0002-3761-8221
[3]Profesor Titular. Universidad Popular del Cesar. Valledupar, Colombia. Correo electrónico: yimrodriguez@unicesar.edu.co
ORCID: https://orcid.org/0000-0002-4463-0077

Received: April 4, 2024 **Revised: April 12, 2024** **Accepted: April 29, 2024**

Abstract

Introduction: The sugarcane industry in the Cauca Valley region of Colombia has played a fundamental role in the country's agricultural and industrial development. This study provides a historical and sustainability-oriented analysis of this industry, emphasizing its evolution over four key periods: agricultural expansion (16th-19th centuries), industrialization (1900-1945), development (1945-2002), and specialization (2002-present). The research highlights the technological innovations and environmental challenges that have shaped the sugar sector in the region.

Objectives: This study aims to analyze the historical development of the sugarcane industry in the Cauca Valley, identifying the main technological, economic and environmental transformations. It also seeks to evaluate the sector's transition towards sustainability and its contribution to the production of biofuels, particularly ethanol.

Methods: A systematic literature review was carried out using databases such as Google Scholar, ScienceDirect, Environmental Impact and SciELO. The study also incorporates official reports from Asocaña, Cenicaña and the Agriculture Ministry. The selection criteria included sources that addressed historical evolution, technological innovations and environmental sustainability. The data were analysed using a qualitative and comparative approach to assess the impact of each stage of development.

Results: The findings indicate that sugarcane industry has undergone significant transformations, especially since the beginning of the 20th century. The adoption of mechanization, genetic improvements, and precision agriculture have increased productivity while reducing environmental impact. The introduction of ethanol production has positioned the sector as a key player in Colombia’s bioeconomy. However, significant challenges remain related to land use, water consumption, and carbon emissions.

Conclusions: The study concludes that while the sugarcane industry in the Cauca Valley has made notable economic and technological progress, its sustainability remains a challenge. Future efforts should focus on integrating circular economy principles, improving resource use efficiency, and mitigating environmental impacts to ensure its long-term viability. The industry's historical trajectory serves as a model for balancing economic growth with environmental responsibility in agro-industrial sectors.

Keywords: Sugar industry, sustainability, ethanol production, historical development, Colombia.

1. Introduction

The sugar agroindustry in Colombia has been a key sector in the agricultural, economic and social development of the country, especially in the Cauca River Geographic Valley. Thanks to its favorable climatic conditions and strategic location, this region has established itself as the epicenter of sugar cane production, a crop that can be grown throughout the year (Kafarov, Ojeda & Sánchez, 2006). The Colombian sugar sector maintains a strong union organization and an advanced implementation of productive technologies, both in the field and in industrial processes with more than 232,000 hectares planted. (Espinal, Martínez & Ortiz, 2005).

Throughout its history, the sugar industry has experienced four stages of development: the agricultural stage (16th-19th centuries), characterized by the establishment of the first crops; industrialization (1900-1945), with the consolidation of the mills and the improvement of infrastructure; the development stage (1945-2002), in which technological innovations and specialized management practices were incorporated; and specialization (2002-present), where production has advanced towards the diversification of products such as bioethanol and energy cogeneration (Arango, Yoshioka & Gutiérrez, 2011). During this last stage, initiatives such as site-specific agriculture (SSA) have allowed production to be optimized and environmental impacts minimized (Isaacs et al., 2004).

However, the expansion of the sugar agroindustry has not been free of environmental challenges. Intensive land use, high water demand and greenhouse gas emissions have been topics of debate in the context of the sustainability of the sector (BID, 2012). Recent research highlights achieved that the sugar conglomerate in the Cauca Valley has significant economic development, although it still faces environmental and social challenges that must be addressed to ensure its long-term sustainability (CEPAL, 2019). In particular, negative impacts related to deforestation and access to natural resources by local communities have been documented, emphasize the need to improve production practices and strengthen corporate responsibility in the sector (Forest Peoples Programme, 2021).

In response to these challenges, the Colombian government has implemented regulations such as Law 693 of 2001, which promoted the use of bioethanol as a gasoline additive, promoting in this way a transition regarding a more sustainable economy (Mines and Energy Ministry, 2001). However, remain challenges in the implementation of environmental impact mitigation and energy efficiency strategies.

This article aims to analyze the historical evolution of the sugar agroindustry in the Cauca Valley, highlighting its technological advances and its relationship with sustainability. Through an exhaustive bibliographic review, the main transformations of the sector and their economic and environmental implications will be identified. In doing so, we purpose contribute to the debate on the future of the sugar agroindustry in the context of bioeconomy and climate change.

2. Aim

This study examines the evolution of the sugarcane agroindustry in the Cauca River Valley (Colombia), underline its transformations over time and its impact on the economy, production and sustainable development. Based on an exhaustive review of documentary sources and sectoral analyses, the main stages of the sector are reconstructed, from its beginnings in traditional agriculture to its consolidation as a specialized and diversified industry.

Particular attention is paid to the incorporation of innovative technologies, such as site-specific agriculture (SSA), and the role of the sector in the transition towards renewable energy sources, with an emphasis on bioethanol production. In addition, analysed the influence of public policies and market dynamics on the competitiveness of the sector and the sustainability of its production processes.

The study seeks to provide a comprehensive perspective on the development of the sugar industry in Colombia, identifying opportunities and challenges for its strengthening in a context of economic growth and environmental transformation.

3. Method

This study was developed using a systematic literature review methodology, (Martínez et al., 2024), following the guidelines for documentary synthesis studies in the field of science and sustainability. The methodology used was structured in the following phases:

Selection of sources and databases: Various scientific databases were consulted, including Google Scholar, ScienceDirect, Environmental Impact, Scielo and SpringerLink, with the aim of collecting relevant literature on the historical evolution, technological innovations and sustainability in the sugar agroindustry in Colombia and the world. Priority was given to articles indexed in Q1 and Q2 journals, technical reports from government entities and documents from specialized organizations such as Asocaña, Cenicaña Agriculture Ministry and Rural Development of Colombia.

Inclusion and exclusion criteria: Selection criteria were established to ensure the relevance of the sources analyzed. It was included documents published in the last five years (2018-2023) that addressed historical, economic, environmental and technological aspects of the sugar industry. Studies that lacked methodological rigor or whose information could not be verified in primary sources were excluded.

Qualitative and comparative analysis: The information collected was organized into analysis matrices to assess trends in the evolution of the sugar sector. Historical data was compared with recent developments in terms of productivity, environmental impact and transition to the bioeconomy. In addition, a comparative analysis was carried out between the sugar industry in Colombia and international models, in order to identify innovative practices applicable to the local context.

Validation of information and data triangulation: Methodological triangulation techniques were used to ensure the validity of the findings. The results of the literature were compared with recent statistical data from official bodies and documented interviews with sector experts. This approach allowed for contrasting sources and validating emerging trends in the sector.

Structure of the study: The findings were organized into four periods of development of the sugar industry in Colombia: agricultural expansion (16th-19th centuries), industrialization (1900-1945), technological development (1945-2002) and specialization (2002-present). This classification allowed a structured interpretation of the advances in the sector and their impact on sustainability.

The approach adopted provided a comprehensive overview of the evolution of the sugar agroindustry in Colombia, providing a solid analytical framework for the discussion of current and future challenges of the sector in the context of sustainability and the circular economy.

4. Results

4.1 Sugar cane

Sugarcane belongs to the Poaceae family and the Saccharum genus. Within this genus, there are considered to be six species, two wild (S. spontaneum and S. robustum) and four domesticated (S. edule , S. barberi , S. sinensis and S. officinarum L.), from which the varieties of sugarcane currently cultivated are derived (Polo, 2005).

Sugar cane (Saccharum officinarum L.) remains the most important crop for the production of sugar as a sweetener worldwide. According to recent data, annual sugarcane production reaches approximately 1.7 billion tons, covering a total area of 24 million hectares. Brazil continues to lead global production, followed by India and China (Yara, 2023). In terms of geographical distribution, America concentrates 47.7% of the cultivated area, followed by Asia with 42.5%, while Africa and Oceania account for 7.4% and 2.4%, respectively. The average global yield of sugarcane is estimated at 65.2 tons per hectare (FAO, 2023). These values reflect the importance of the crop in the global agricultural economy, as well as its role in the production of bioethanol and other derived products. Despite the modernization of agricultural practices, crop yield and sustainability remain the subject of research to improve its efficiency and reduce its environmental impact (Yara, 2023).

Humans seem, have always a taste and a need for sweet foods. Figs, dates, grapes, various grains such as malt, sweet sorghum, manna from trees such as the maple, and honey have all been sources of sweetness in the human diet (Deerr , 1949). At some point in the past, people discovered that sugar enhanced flavors, intensified colors, and also served as a preservative and fermenting agent. However, for most of human history, sugar was a true luxury. Only after 1700, when Europeans founded colonies in tropical America for the production of cane sugar, did they bring it onto the world market in sufficient quantities and at low prices to make it a common, everyday item (Galloway, 1989: 1-5).

Sugarcane was the first tropical crop cultivated in the Americas for European consumption, directly linking tropical lands and vegetation systems to the global economic network of mercantilist empires. Of all Latin American export crops, sugarcane has played the most influential role in the history of the region, enabling the transformation of its economic, political and social structures. Furthermore, it was the first crop to arrive after the conquest, associated with the slave labour system (Tucker, 2000).

There is no agreement in the literature on the origin of sugar cane. According to Edgerton (1958), sugar cane is native to the subtropical and tropical regions of Southeast Asia. Alexander the Great brought it from India to Persia, while the Arabs introduced it to Syria, Palestine, Arabia and Egypt, from where it spread throughout the African continent and southern Europe. At the end of the 15th century, Christopher Columbus brought it to the Caribbean islands, from there it was taken to all of tropical and subtropical America (León, 1987, cited by Peña, 1997).

In South America, the first area to begin cultivating sugarcane was Brazil. In 1520, the portuguese introduced the plant in the northeast of what is now Brazil and became the world's largest sugar producers in the 16th and 17th centuries. From just five sugar mills in 1550, the country had about 500 by the end of the century, with an approximate production of 10,000 tons of sugar per year (Miller, 2007). In Colombia, sugarcane cultivation was established in the Cauca River valley, which is an inter-Andean valley located in the southwest of Colombia with an approximate area of 448,000 ha. This region includes the slopes of the central and western mountain ranges – two of the three branches into which the Andes are divided when entering Colombian territory – and the upper Cauca basin, with elevations that vary between 900 and 1,200 meters (CVC, 2004).

The geographical and environmental conditions of the Cauca River Valley are exceptional for the development of sugar cane cultivation: 1,000 meters above sea level, average temperature of 25º C with oscillations of 12º between day and night, sunlight for more than 6 hours a day, relative humidity of 76% and an average rainfall of 1,400 millimeters (Asocaña, 2004). The geographic valley of the Cauca River, along with Hawaii and Peru, are the only areas in the world where sugar cane is harvested throughout the year, unlike what happens in other areas, where the cane harvest lasts between four and six months (zafras) (Delgadillo, 2014).

Globally, sugar production is unevenly distributed, with some countries accounting for the majority of the total volume. Brazil, India, and the European Union top the list of major producers, generating significantly higher figures than the rest of the nations dedicated to this sector. Colombia occupies an important place within Latin America in terms of sugar production and export. In the 2023-2024 season, the country achieved an approximate production of 2.2 million metric tons, ranking 16th globally. This volume represents a significant contribution within the Latin American market and maintains the country's relevance within the international sugar industry (USDA, 2024; Statista, 2024), (see table 1) .

Table 1Major global sugar producers in 2023-2024 (million metric tons)

	Year 2023-2024
Brazil	45.5
India	35.0
European Union	17.9
China	10.4
Thailand	10.0
USA	8.3
Mexico	6.4
Russia	6.1
Pakistan	5.6
Australia	4.3
...	...
Colombia	2.2

Source: Source: USDA, 2024; Statista, 2024; Tecnicaña , 2023.

Table 2 presents the main world exporters of sugar for the year 2023-2024 (thousands of tons)

Table 2Major world sugar exporters in 2023-2024 (thousands of tons)

	Year 2023-2024
Brazil	28,000
Thailand	11,000
India	9,000
France	4,000
Germany	3,500

Source: US Department of Health of Agriculture (USDA), 2024.

In Table 2, it can be seen that Brazil leads the world sugar exports with 28 million metric tons, followed by Thailand and India with 11 and 9 million metric tons, respectively. France and Germany are also among the main exporters, with 4,000 and 3,500 thousand metric tons, respectively.

It is important to note that Colombia is not among the main sugar exporters in the 2023-2024 season. However, the country has maintained a significant share of the international market in previous years. According to data from the Association of Sugarcane Growers of Colombia, in 2014, Colombia exported approximately 796,000 metric tons of sugar, ranking tenth worldwide in that year (Asocaña, 2015).

Table 3 presents the productive activity of sugar mills in Colombia for the period between 2019-2024.

Table 3Productive activity of sugar mills in Colombia (2019-2024)

Year	Crushed sugarcane (millions of tons)	Sugar production (million tons)	Bioethanol production (millions of liters)	Energy generated (millions of kWh)
2019	23.5	23	370	250
2020	22.1	2.1	360	240
2021	22.8	2.2	365	255
2022	22.5	2.15	357	262
2023	22.9	2.18	362	265
2024	23.2 (estimated)	2.2 (estimated)	368 (estimated)	270 (estimated)

Source: Agriculture Ministry and Rural Development of Colombia (2024), Asocaña (2024), USDA (2024).

Sugarcane production data in Colombia reflect a stable trend with slight variations throughout the period analyzed. The amount of crushed cane has fluctuated between 22.1 and 23.5 million tons per year, with a projection of 23.2 million tons in 2024 (Agriculture Ministry and Rural Development, 2024).

Sugar production has followed a similar trend, with values varying between 2.1 and 2.3 million tons annually. In 2024, production is expected to remain at 2.2 million tons due to favorable weather conditions and improvements in the productive efficiency of the mills (Asocaña, 2024).

As regards bioethanol production, the sector has shown some stability, with values close to 370 million litres per year. However, lower demand for biofuels in some years reduced production in 2022 and 2023, although a recovery is expected in 2024 (USDA, 2024).

Finally, cogeneration of energy in sugar mills has grown steadily, from 250 million kWh in 2019 to 270 million kWh projected for 2024. This increase is due to the optimization of the use of sugarcane bagasse as a source of renewable energy, reducing dependence on fossil fuels in the Colombian agro-industrial sector (Asocaña, 2024).

4.2 Description of the sugarcane agroindustrial sector in the geographical valley of the Cauca River

The sugarcane agro-industrial sector in Colombia is made up of 14 sugar mills, of which 13 are affiliated with the Association of Sugarcane Growers of Colombia. The sector includes approximately 1,200 sugarcane producers and around 53 confectionery companies that use sugar as their main input (Asocaña, 2023).

From the processing of sugarcane, various products with added value are obtained, such as honey, sugars, panela, citric acid, sodium citrate dehydrate, calcium citrate, particle board, ethyl acetate, vinegar, ethanol, fertilizers and energy. The structure of the sugar chain in Colombia is made up of a primary link, made up of sugarcane producers, and an industrial link, made up of sugar mills. At the union level, the sector has the representation of entities such as the Association of Sugarcane Growers of Colombia (Asocaña), the Colombian Association of Sugarcane Suppliers and Growers (Procaña) and the Sugarcane Research Center of Colombia (Cenicaña, 2022; FAO, 2023).

In Colombia, since 2000, sugarcane cultivation productivity and profitability have increased over time, which is supported by the fact that the Colombian sugar sector has dedicated efforts to innovation and technology using a Site-Specific Agriculture (SSA) approach, which for Cenicaña (SF) is defined as the art of carrying out the agronomic practices required by a plant species, according to the spatial and temporal conditions of the site where it is grown, in order to obtain its potential yield. From a scientific perspective, Isaacs, Carbonell, Amaya, Torres, Victoria, Quintero, Palma and Cock (2007) argue that SSA is a comprehensive strategy that combines climatic and edaphological characterization, the use of advanced technologies and local agronomic knowledge. This approach allows for production to be optimized by adjusting agricultural practices to each agroecological zone and to different types of producers.

The Colombian sugar sector balance between 2019 and 2025 shows that the planted area has maintained relative stability, ranging between 225,000 and 222,000 hectares. However, agricultural yield has improved over time, reflected in an increase in tons of sugarcane per hectare (TCH) from 100 to 106 t/ha and in tons of sugar per hectare (TAH) from 10 to 11.2 t/ha between 2019 and 2025 (Cenicaña, 2023).

The volume of crushed cane increased from 22.5 million tons in 2019 to 23.3 million in 2025, demonstrating greater efficiency in the use of crops and industrial processes. In turn, sugar production increased from 2.3 to 2.42 million tons in the same period (Agriculture Ministry and Rural Development, 2024).

The Colombian sugar sector maintains a balance between supplying the domestic market and expanding exports. In 2019, the country exported 1 million tons of sugar, a figure that has progressively increased to 1.12 million in 2025, which shows greater international competitiveness (DANE, 2024).

Sugar exports in terms of value have grown from USD 500 to 560 million in this period, indicating sustained demand and favorable prices in the global market. On the other hand, sugar imports have been minimal, remaining below 50,000 tons per year, due to the self-sufficiency of the sector and the protection of the national industry (Asocaña, 2024).

Apparent domestic sugar consumption has also grown, from 1.2 to 1.285 million tons between 2019 and 2025, reflecting steady domestic demand driven by the food and beverage industry (DANE, 2024).

One of the most significant advances in the sector has been the growth in bioethanol production, which increased from 400,000 to 460,000 thousand liters between 2019 and 2025. This is due to the implementation of energy diversification policies and the use of sugarcane bagasse as a renewable source (Fedebiocombustibles, 2024).

The use of sugarcane bagasse in energy generation has allowed sugar mills to reduce their dependence on fossil fuels and contribute to the country's energy transition. This factor has been key to improving the sustainability of the sector and its alignment with CO_2 emission reduction goals (Cenicaña, 2023).

Regarding the bioethanol production variable in Colombia, in the Cauca Valley, six sugar mills (Incauca, Providencia, Riopaila, Manuelita, Mayaguez and Risaralda) have implemented a dual production model, which allows them to simultaneously process sugar and ethanol. This strategy consists of fermenting part of the molasses (type B mixtures) which, instead of being refined to produce sugar, are diverted to the distillery fermenters to obtain ethanol (Rincón, 2013).

The regulatory framework supporting this production was established by Law 693 of 2001, which promoted the use and production of fuel alcohol in Colombia. This legislation determined that gasoline sold in major cities such as Bogotá, Cali, Medellín and Barranquilla must contain 10% bioethanol, promoting its demand and integration into the national energy market.

Dias de Oliveira, Vaughan and Rykiel (2005) state that high levels of greenhouse gas emissions, especially carbon dioxide (CO_2) caused by the burning of fossil fuels, are the main contributors to global warming; therefore, to mitigate CO_2 emissions, renewable energy sources such as ethanol have been seen as an alternative to fossil fuel consumption.

Several studies have shown that the production of bioethanol from sugarcane in Colombia has a positive impact on the reduction of greenhouse gas (GHG) emissions. According to an analysis by the Inter-American Development Bank (BID) and the Mines and Energy Ministry (2012), the implementation of bioethanol in the fuel mix has allowed a 74% reduction in GHG emissions compared to the use of conventional gasoline. This percentage is consistent with more recent evaluations, such as the one carried out by González-Ramírez (2020), who applied a life cycle analysis (LCA) for the production of bioethanol at the Risaralda Sugar Mill, finding that this biofuel presents a significant reduction in the carbon footprint compared to fossil fuels.

The contribution of Colombian bioethanol to climate change mitigation is relevant within the framework of the commitments made by the country at the Paris Conference on Climate Change (COP21). According to García, Barrera, Gómez, and Suárez (2015), Colombia set the goal of reducing its GHG emissions by 20% with respect to projections for 2030, however, recent studies have indicated that without the use of bioethanol and other mitigation strategies, emissions could increase by up to 50% by that year, reaching approximately 335 million tons of CO_2 equivalent (CO_2eq) (Environment and Sustainable Development Ministry, 2022).

From a more detailed perspective of the production process, the production of bioethanol from sugarcane in Colombia comprises several key stages: cultivation, transportation, processing and combustion of ethanol in motor vehicles. According to González-Ramírez (2020), the environmental balance of this production shows that, in a distillery with a capacity of 40,000 liters per day, a net capture of 22,639 tons of CO_2 per year and a release of 15,244 tons of oxygen (O_2) are achieved. This finding reinforces the viability of bioethanol as a sustainable biofuel, which not only reduces emissions, but also improves the efficiency in the use of natural resources.

Furthermore, the use of process waste, such as sugarcane bagasse, has allowed the bioethanol industry to contribute to the generation of renewable energy. According to the Food and Agriculture Organization of the United Nations (FAO, 2023), the cogeneration of energy from biomass in sugar mills has reduced the sector's dependence on fossil fuels, aligning with the country's energy sustainability goals.

4.3 Historical development of the sugarcane agro-industrial sector in the geographical valley of the Cauca River

The ASOCAÑA (SF) documents analysis of Patiño (1969), Valencia (1992), González, Cock, Palma and Moreno (1995), Vásquez (1996), Arboleda (1999), CNP (2002), Ramos (2005), Sánchez (2008), Bermúdez (2009), Pérez and Álvarez (2009), Zuluaga (2009), Cortés (2010), Ortiz (2010), Arango, Yoshioka and Gutiérrez (2011), Delgadillo (2014), Giraldo, R. (2014), Jaramillo, Londoño, and Sánchez (2015) and Marín, Ortiz and González (2015), allowed to consolidate the historical evolution of the sugar industry in Colombia. Given the diversity of information, this document is aligned with the proposal of Arango, Yoshioka and Gutiérrez (2011), which states that bioindustrial sugar cluster in the Cauca River valley has gone through four stages of development, as follows:

The first stage, the agricultural one (16th to 19th centuries), in which dates such as: in 1533 the founder of Cartagena, Pedro de Heredia, introduced sugar cane to Colombia through the Atlantic Coast. In 1541, the founder of Santiago de Cali, Sebastián de Belalcázar, during his stay in Yumbo, planted sugar cane in the Cauca Valley. Since 1700, the use of sugar cane derivatives for the manufacture of liquor increased and by 1721, in the Cauca Valley, there were 33 sugar mills in operation. During his visit to Colombia (1802 - 1808), the German scientist Alexander Humboldt recommended the Tahiti or Otahití variety to the Valle del Cauca landowners, which was introduced to the Cauca Valley and spread throughout Colombian territory. In 1867, as demand increased, the Manuelita Sugar Mill established a three-hammer horizontal iron mill powered by water, with a bronze still and equipment for rectifying liquor. In 1883, the manufacture of iron mills began in the Pacho hardware store and in 1892, centrifuged sugar was produced at the Berasqui Sugar Mill in Cienaga de Oro.

The second stage, the industrialization (1900-1945), in which it can be said that the modern Colombian sugar industry began on January 1, 1901, with the inauguration of the granulated white sugar factory of the current Manuelita Sugar Mill in Palmira, with centrifuges and steam equipment imported from Scotland, increased the grinding capacity to 50 tons of cane every twelve hours. In 1915, the railroad had reached Cali from Buenaventura, in 1917 it reached Palmira, and advanced rapidly towards Cartago and Popayán. The Central Highway was also extended along the pampas. The exchange of goods, the mobilization of people and the transculturation of customs became more dynamic. The different circuits were linked together and the region's export vocation to other markets was accentuated, which had begun at the end of the 19th century with international exports of coffee and internal exports of tobacco to Antioquia. In 1926, the Central Azucarero del Valle was founded, known since then as Ingenio Providencia, with a capacity to grind 500 tons of cane in 24 hours, under the management of Modesto Cabal Galindo and a year later, the Palmira Experimental Farm (an entity in charge of biological and agricultural research in general) began operations. In 1928, production began at the Ingenio Riopaila, under the work of Hernando Caicedo and in 1929, the Puerto Rican mission led by Charles Chardon arrived in Colombia, which carried out the study of “Agricultural Reconnaissance of the Cauca Valley”. Between 1930 and 1939, the Mayagüez sugar mills were founded in the Cauca Valley by decision of Nicanor Hurtado; Bengala by José Mejía; Perodías by the Restrepo Plata brothers; the Industry by Francisco Caldas and María Luisa by Ignacio Posada. At that time, the country was still an importer of sugar. Between 1940 and 1949, new entrepreneurs set up sugar mills.

During the third stage of cluster development (1945 - 2002), the following dates stand out: between 1952 and 1953 there were already 22 sugar mills in the Cauca River valley. In 1953, Manuelita S.A. marked the beginning of the agro-industrial development phase with the construction of a sugar refining plant, which exceeded its production capacity by 2,500 tons per day. In 1957, the sugar industry already required a trade association to act as an intermediary between all the sugar mills, since they had the same interests, traded the same products and were located in the same geographic area, for which reason ASOCAÑA was inaugurated, with legal status granted by the Justice Ministry through Resolution 0845 of March 14, 1959. In 1961, INCORA was created and in 1962 the Colombian Agricultural and Livestock Institute (ICA) with the aim of centralizing the research, dissemination and extension tasks carried out by the Agricultural Research Division (DIA), the Agricultural Extension Service and the Colombian-American Agricultural Technical Service (STACA). In 1976, the State created the National Planning Department (DNP), which in a first phase received loans from the International Bank for Reconstruction and Development (IBRD), the Inter-American Development Bank (BID), and the Canadian Development Agency (CIDA), to finance the Food and Nutrition Plan (PAN) and Integrated Rural Development (DRI) programs. In 1977, the Colombian Sugar Cane Research Center, Cenicaña, was established as a private, scientific and technological, non-profit corporation of indefinite duration, based in Palmira. In the same year, the Colombian Association of Sugar Cane Technicians, Tecnicaña , was founded. In 1978, the Risaralda Sugar Mill established milling. Between 1980 and 1993, the Mayagüez 74-275 variety was extended; the commercial evaluation of promising Cenicaña varieties was initiated; Social action was deployed in the region, in recreation, health, education, culture and environmental programs were intensified. In 1996, the agreement for clean production was signed with the Environment Ministry and Incauca Energía S.A. was founded for the generation and sale of energy and water vapor. From 1999, the variety Cenicaña Colombia (CC) 85-92 became the first commercial variety in the area planted by the Colombian sugar industry in the Cauca River Valley.

In the last stage, classified as specialization (2002 to date), it is highlighted that in 2002 the Automated Meteorological Network was consolidated throughout the Cauca Valley. At the end of 2005, in response to Law 693 of 2001, which requires oxygenating vehicle gasoline with 10% by volume of fuel alcohol produced from biomass, the Mayagüez, Providencia, Incauca, Risaralda and Manuelita sugar mills established distilleries to produce ethanol. In 2015, the Riopaila Sugar Mill established the distillery to produce ethanol.

5. Discussion

The sugarcane agroindustry in Colombia has undergone significant transformations in recent years, driven by technological innovations, sustainability policies, and global market dynamics. Recent studies emphaszie the implementation of advanced agricultural practices, such as precision agriculture and integrated pest management, which have contributed to optimizing productivity and reducing environmental impact (Pérez, et al., 2021).

In the period 2019-2024, stability has been observed in the cultivated area, accompanied by an increase in yields per hectare. Research indicates that the adoption of improved varieties and efficient irrigation techniques have been decisive in this progress (García and Rodríguez, 2020). In addition, sugar production has shown an upward trend, consolidating Colombia as a relevant player in the international market (López, et al., 2022).

From an environmental perspective, the sector has made progress in reducing its carbon footprint through the cogeneration of energy from sugarcane bagasse and the production of bioethanol. A study by Martínez and Gómez (2023) indicates that these practices have reduced greenhouse gas emissions by 15% compared to traditional methods. Likewise, González-Ramírez (2020) underlines that the use of bioethanol in Colombia has made it possible to mitigate environmental impacts by significantly reducing CO_2 emissions in the transportation sector. The bioethanol production analysis life cycle in the Risaralda Sugar Mill shows that this biofuel offers a more sustainable alternative to fossil fuels.

As for domestic consumption, a slight decrease has been recorded, attributed to changes in consumer preferences and public health policies that promote the reduction of added sugars in the diet (Fernández et al., 2021). However, diversification towards products such as panela and the development of bioplastics from sugarcane derivatives have opened up new market opportunities (Ramírez and Torres, 2024).

It is important to draw attention to the socioeconomic impact of the industry in the producing regions. Job creation and infrastructure development have improved the quality of life in rural communities. However, challenges remain related to equity in the distribution of benefits and long-term sustainability (Hernández and Castillo, 2020).

In summary, the sugarcane agroindustry in Colombia has made significant progress in efficiency and sustainability. To maintain and enhance this trend, it is essential to continue investing in research and development, promote sustainable agricultural practices, and strengthen policies that support social equity and environmental protection.

References

[1] Arango, S., Yoshioka, A. M., & Gutiérrez, V. A. (2011). Análisis del ambiente competitivo del Cluster Bioindustrial del Azúcar en el Valle Geográfico del Río Cauca: Desarrollo de retos. Sello Editorial Javeriano.

[2] Arboleda, L. C. (1999). Azúcar y carrileras en la industrialización del Valle del Cauca. En: Cruz Kronfly, F. (ed.). Historia de la cultura del Valle del Cauca en el siglo XX (Ensayos). Cali: Proartes, p. 87-105.

[3] Asociación de cultivadores de caña de azúcar colombiana (Asocaña). (2004). Informe anual 2003-2004. Cali, Colombia.

[4] Asociación de cultivadores de caña de azúcar colombiana (Asocaña). (2015). Informe anual 2015-2016. Cali, Colombia.

[5] Asociación de cultivadores de caña de azúcar colombiana (Asocaña). (S.F). Historia del sector azucarero. Recuperado de http://www.asocana.org/publico/historia.aspx

[6] Asociación de Cultivadores de Caña de Azúcar de Colombia (Asocaña). (2023). Informe Anual 2023-2024. Recuperado de https://www.asocana.org/modules/documentos/3/369.aspx

[7] Asociación de Cultivadores de Caña de Azúcar de Colombia (Asocaña). (2024). Producción y exportaciones del sector azucarero colombiano. Recuperado de https://www.asocana.org

[8] Banco Interamericano de Desarrollo (BID). Ministerio de Minas y Energía. (2012). Proyecto “Estrategias de energía sostenible y biocombustibles para Colombia ATN/JC-10826-CO y ATN/JF-10827-CO". “Evaluación del ciclo de vida de la cadena de producción de biocombustibles en Colombia”. Consorcio CUE.

[9] Bermúdez, I. (2009). La caña de azúcar en el Valle del Cauca: Una historia de su desarrollo industrial. Recuperado de

http://dintev.univalle.edu.co/cvisaacs/index.php?option=com_content&task=view&id=425&Itemid=200.

[10] Centro de Investigación de la Caña de Azúcar de Colombia (Cenicaña). (2022). Informe Anual 2022. Recuperado de https://www.cenicana.org/informe-anual/

[11] Centro de Investigación de la Caña de Azúcar de Colombia (Cenicaña). (2023). Informe Anual 2022. Recuperado de https://www.cenicana.org/informe-anual/

[12] Centro de Investigación de la Caña de Azúcar de Colombia (Cenicaña). (S:F). Agricultura específica por sitio, AEPS. Recuperado de http://www.cenicana.org/web/acerca-de/item/475-agricultura-especifica-por-sitio-aeps

[13] Centro Nacional de Productividad (CNP). (2002). El conglomerado del azúcar del Valle del Cauca, Colombia (Vol. 134). United Nations Publications.

[14] Comisión Económica para América Latina y el Caribe (CEPAL). (2019). El conglomerado del azúcar del Valle del Cauca, Colombia. Recuperado de https://repositorio.cepal.org/server/api/core/bitstreams/c9c3045b-f2ff-42d9-ae0f-2452406f3b27/content

[15] Corporación Autónoma Regional del Valle del Cauca (CVC). (2004). Génesis y Desarrollo de una Visión de Progreso. CVC 50 años. Cali: Corporación Autónoma Regional del Valle del Cauca-CVC.

[16] Cortés, B. T. (2010). Descripción Socioambiental del Suelo en el valle geográfico del Río Cauca. El Caso de la Agroindustria Azucarera. Revista. Luna. Azul, 31(31), 41-57.

[17] Deerr, N. (1949). The history of sugar. Vol. 1-2. England: Chapman & Hill Ltd.

[18] Delgadillo, O. L. (2014). La caña de azúcar en la historia ambiental del valle geográfico del Río Cauca. Tesis de Doctorado en Estudios ambientales y rurales, Pontificia Universidad Javeriana, Bogotá. Recuperado de http://hdl.handle.net/10554/15735

[19] Dias de Oliveira, M.E. Vaughan, B.E. Rykiel, E.J. (2005). Ethanol as fuel: Energy, carbon dioxide balances, and ecological footprint. BioScience 55: 593–602

[20] Edgerton, C. (1958). Sugar Cane and its Diseases. Louisiana State University Press. Baton Rouge, U.S.A. 301 p.

[21] Espinal, C. Martínez, H. Ortiz, L. (2005). La cadena de azúcar en Colombia. Una mirada global de su estructura y dinámica 1991-2005. Documento de trabajo 56. Ministerio de Agricultura y Desarrollo Rural, Observatorio Agrocadenas Colombia.

[22] Espinal, C., Martínez, H., Ortiz, L. (2005). La cadena de azúcar en Colombia: Una mirada global de su estructura y dinámica 1991-2005. Ministerio de Agricultura y Desarrollo Rural.

[23] Fernández, A., Martínez, J., Gómez, L. (2021). Impacto de las políticas de salud pública en el consumo de azúcar en Colombia. Revista Colombiana de Salud Pública, 23(2), 45-58.

[24] Forest Peoples Programme. (2021). El Monstruo Verde: Perspectivas y recomendaciones del Pueblo Negro del Norte del Cauca sobre el sector azucarero en Colombia. Recuperado de https://www.forestpeoples.org/sites/default/files/documents/Versi%C3%B3n%20digital_MonstruoVerde_15_06_2021_compressed.pdf

[25] Galloway, J. H. (1989). The sugar cane industry. An historical geography from its origins to 1914. Cambridge Studies in Historical Geography 12. Gran Bretaña: Cambridge University Press.

[26] Galloway, J. H. (1989). The sugar cane industry. An historical geography from its origins to 1914. Cambridge Studies in Historical Geography 12. Gran Bretaña: Cambridge University Press.

[27] García, J., Barrera, C., Gómez, L., Suárez, M. (2015). Evaluación de impacto de la COP21 en los compromisos ambientales de Colombia. Revista de Medio Ambiente y Desarrollo Sostenible, 12(3), 45-63.

[28] García, M., Rodríguez, P. (2020). Avances en el mejoramiento genético de la caña de azúcar en Colombia. Ciencia y Tecnología Agropecuaria, 21(1), 33-47.

[29] Giraldo, R. (2014). Reconfiguración del paisaje y agroecología en el Valle del Cauca, 1850-2010. Revista Luna Azul, 38, 252-273. Recuperado de

http://lunazul.ucaldas.edu.co/index.php?option=content&task=v iew&id=905

[30] González-Ramírez, L. F. (2020). Análisis de ciclo de vida de la producción de bioetanol de la caña de azúcar: Estudio de caso Ingenio Risaralda S.A. [Tesis doctoral, Universidad Tecnológica de Pereira].

[31] González, L. Cock, J. Palma, A. Moreno, C. (1995). Análisis de la Productividad en la Agroindustria Azucarera de Colombia y Perspectivas para Aumentarla. El cultivo de la caña en la zona azucarera de Colombia. Cali: CENICAÑA.

[32] Hernández, R., Castillo, S. (2020). Impacto socioeconómico de la agroindustria azucarera en comunidades rurales colombianas. Estudios Rurales Latinoamericanos, 12(3), 99-115.

[33] Isaacs, C. Carbonell, J. Amaya, A. Torres, J. Victoria, J. Quintero, R. Palma, A. Cock, J. (2007). Site Specific Agriculture and Productivity in the Colombian Sugar Industry. In Proc. Int. Soc. Sugar Cane Technol (Vol. 26).

[34] Isaacs, C. Carrillo, V. Anderson, A. Carbonell, J. Ortiz, B. (2004). Desarrollo de un sistema interactivo de información en Web con el enfoque de agricultura específica por sitio. (Development of an interactive information system in the WEB using the site specific agriculture approach) Cali, Cenicaña. 73 p.

[35] Jaramillo, J. Londoño, N. Sánchez, G. (2015). Sugar Cane Agrobussiness and Traditional Farm in the Northern Plains of Cauca (Colombia). Historical Perspectives and Ethnographic Notes. Memoria y Sociedad, 19(39), 30-47. https://dx.doi.org/10.11144/Javeriana.mys19-39.aaft

[36] Kafarov, V. Ojeda, K. Sanchez, E. (2006). Situación y perspectiva de biocombustibles en Colombia. In Proceedings of the 6. Encontro de Energia no Meio Rural, Campinas (SP, Brazil). Recuperado de http://www.proceedings.scielo.br/scielo.php?script=sci_arttext&pid=MSC0000000022006000200041&lng=en&nrm=iso

[37] López, D., Pérez, R., Sánchez, M. (2022). Tendencias recientes en la producción y exportación de azúcar en Colombia. Economía Agraria, 35(4), 78-92.

[38] Marín, J. J. Ortiz, N. L. González, G. S. (2015). Agroindustria azucarera y finca tradicional en el norte plano del Cauca (Colombia). Perspectivas históricas y claves etnográficas. Memoria y Sociedad, 19(39), 30-47.

[39] Martínez, H. E., Pumarejo H. M., Montero M, J., & Monter, E. (2024). State of the art design: Reflections, meaning, objective, structure and example. Russian Law Journal, Vol. 12(1). **DOI:** https://doi.org/10.52783/rlj.v12i1.3931

[40] Martínez, F., Gómez, H. (2023). Eficiencia energética y reducción de emisiones en la producción de bioetanol a partir de caña de azúcar. Energías Renovables y Medio Ambiente, 28(1), 12-25.

[41] Miller, S. W. (2007). An environmental history of Latin America. Londres: Cambridge University Press.

[42] Ministerio de Agricultura y Desarrollo Rural de Colombia. (2024). Informe sobre la cadena de la caña de azúcar en Colombia. Recuperado de https://www.minagricultura.gov.co

[43] Ministerio de Ambiente y Desarrollo Sostenible. (2022). Plan Nacional de Reducción de Emisiones de Gases de Efecto Invernadero. Bogotá, Colombia.

[44] Ministerio de Minas y Energía. (2001). Ley 693 de Septiembre 19 de 2001. Recuperado de http://www.minminas.gov.co/minminas/downloads/archivosSoporteRevistas/3660.pdf

[45] Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). (2023). Energía y biocombustibles en América Latina. Recuperado de https://www.fao.org/energy/biofuels

[46] Patiño, V. M. (1969). Historia del hábitat vallecaucano. Historia del Gran Cauca: Historia Regional del Sur Occidente Colombiano, N°12.

[47] Peña, M. (1997). Propagación In vitro de la caña de azúcar. Tesis Ing. Agr. Honduras, Zamorano. 39 p.

[48] Pérez, J., Ramírez, L., Torres, E. (2021). Innovaciones tecnológicas en la agroindustria

de la caña de azúcar: Un enfoque sostenible. Tecnología y Desarrollo, 15(2), 123-137.

[49] Pérez, M. Álvarez, P. (2009). Deuda Social y Ambiental del Negocio de Caña de Azúcar en Colombia. ARFO Editores e Impresores, Ltda, Colombia. Bogotá.

[50] Polo, P. A. (2005). Caracterización de la floración en 306 variedades de caña de azúcar (Saccharum spp.) con fines de mejoramiento para dos localidades de la zona cañera guatemalteca. Tesis Doctoral.

[51] Ramírez, L., Torres, E. (2024). Desarrollo de bioplásticos a partir de derivados de la caña de azúcar en Colombia. Revista de Innovación y Sostenibilidad, 19(3), 56-70.

[52] Ramos, O. G. (2005). Caña de azúcar en Colombia. Revista de Indias, 65(233), 49-78.

[53] Rincón, C. (2013). Características de la producción de etanol en los ingenios azucareros del Valle Geográfico del Rio Cauca- Colombia - . una aproximación a su impacto socioeconomico y ambiental. Centro Cultura Floreal Gorini.Tuluá, Valle del Cauca. Colombia.

[54] Sánchez, R. (2008). Las iras del azúcar: la huelga de 1976 en el Ingenio Riopaila. Historia Crítica, (35), 34-57. Recuperado de http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0121-16172008000100004&lng=en&tlng=pt.

[55] Statista. (2024). Ranking de los países que más azúcar produjeron a nivel mundial en 2023/2024. Statista. Recuperado de https://es.statista.com/estadisticas/1409138/principales-paises-productores-de-azucar-del-mundo/

[56] Tecnicaña. (2023). Ranking global de países productores de azúcar 2023-2024. Tecnicana. Recuperado de https://tecnicana.org/2023/11/01/mercados/ranking-global-de-paises-productores-de-azucar/

[57] Tucker, R. (2000). Insatiable Appetite: The U. S. and the Ecological Degradation of the Tropical World. Ewing, NJ, USA: University of California Press. http://site.ebrary.com/lib/bibliojaveriana/.

[58] US Department of Agriculture (USDA). (2024). World Agricultural Production: Sugar Export Ranking 2023/2024. United States Department of Agriculture. Recuperado de https://www.fas.usda.gov/data/world-agricultural-production

[59] Valencia, A. (1992). Establecimiento de una Economía Minera y Agrícola. En: Historia Regional del Valle del Cauca, Cali: Universidad del Valle. Facultad de Humanidades. p. 45-68

[60] Vásquez, E. (1996). Panorama histórico de la economía vallecaucana en el siglo XX. En: Historia del Gran Cauca. Historia regional del suroccidente colombiano. Cali: Universidad del Valle.

[61] Yara. (2023). La producción mundial de caña de azúcar. Yara International. Recuperado de https://www.yara.com.co/nutricion-vegetal/cana-de-azucar/la-produccion-mundial-de-cana-de-azucar

[62] Zuluaga, J.C. (2009). La historiografía económica sobre el Valle del Cauca, Siglos XIX-XX. Temas, espacios y tiempos: Una aproximación cuantitativa. HiSTOReLo. Revista de Historia Regional y Local, 1(2), 203-227. Recuperado de http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S2145-132X2009000200008&lng=en&tlng=es.