

ANÁLISIS DEL COMPORTAMIENTO ECONÓMICO Y DESAFÍOS DEL SECTOR PANELERO EN LA REGIÓN DEL CATATUMBO

ANALYSIS OF THE ECONOMIC PERFORMANCE AND CHALLENGES OF
THE PANELA SECTOR IN THE CATATUMBO REGION

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RESUMEN

El artículo explora el comportamiento económico y los desafíos del sector panelero en la región del Catatumbo, Colombia, destacando su relevancia como motor de desarrollo rural. Mediante una revisión bibliográfica sistemática, se analizan las características productivas del sector, incluyendo la prevalencia de técnicas tradicionales y las limitaciones que enfrentan los productores para competir en mercados nacionales e internacionales. El estudio identifica oportunidades de expansión, como la creciente demanda de productos orgánicos, y propone

PALABRAS CLAVE

Panela, Catatumbo,
desarrollo rural,
modernización
tecnológica,
competitividad.

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estrategias para fortalecer el sector, incluyendo modernización tecnológica creación de una marca colectiva que diferencie la panela del Catatumbo. Además, se discuten las implicaciones de las políticas públicas y el papel de la asociatividad en la sostenibilidad del sector. El artículo concluye que, a pesar de los desafíos, el sector panelero del Catatumbo tiene un potencial significativo para contribuir al desarrollo económico regional.

ABSTRACT

This article explores the economic performance and challenges of the panela sector in the Catatumbo region of Colombia, highlighting its relevance as an engine of rural development. Through a systematic literature review, it analyzes the productive characteristics of the sector, including the prevalence of traditional techniques and the constraints faced by producers to compete in national and international markets. The study identifies opportunities for expansion, such as the growing demand for organic products, and proposes strategies to strengthen the sector, including technological modernization and the creation of a collective brand that differentiates panela from Catatumbo. It also discusses the implications of public policies and the role of associativity in the sustainability of the sector. The article concludes that, despite the challenges, the Catatumbo panela sector has significant potential to contribute to regional economic development.

KEYWORDS

Panela, Catatumbo, rural development, technological modernization, competitiveness.

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

INTRODUCTION

Colombia stands out as one of the world's leading producers of panela, ranking second after India. Panela, an unrefined whole cane sugar obtained from the juice of sugarcane (*Saccharum officinarum* L.), is a staple in the Colombian diet and represents a significant source of income for thousands of rural families (Buitrago Ardila, 2019). In the Catatumbo region, panela production is not only an economically relevant activity but also a deeply rooted cultural tradition.

Rural agricultural industries in Latin America and the Caribbean are notable for their production of panela, a food product made from sugarcane juice (*Saccharum officinarum*). Global production is estimated at nearly 13 million tons per year, distinguishing it from brown and white sugar due to its chemical composition, which includes not only sucrose but also fructose, glucose, minerals, vitamins, and protein compounds (FAO, 2019).

In Latin America, panela holds great importance in countries such as Colombia, Brazil, Ecuador, Peru, and Venezuela. In these nations, its production is an essential agricultural activity, particularly in rural and mountainous areas, where peasant families combine sugarcane cultivation with livestock farming and other agricultural activities. This production model allows for the utilization of family labor and the optimization of local resources (Pérez Lobo & Rojas Contreras, 2020).

Colombia ranks as the world's second-largest producer of panela, behind India, with substantial production that meets both domestic and international demand. Colombian panela exports have found buyers in Europe, North America, and other regions where the demand for natural and organic products is growing (Rodríguez *et al.*, 2020; Cadavid, 2007). However, panela production faces challenges related to competitiveness and the modernization of production techniques.

In India, panela production, known as Jaggery, is a significant industry that employs millions of people and contributes substantially to the rural economy. It is produced using traditional methods, and its consumption is deeply rooted in Indian

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

culture and cuisine (FAO, 2019).

Brazil is also a notable producer of panela, locally referred to as Rapadura. Rapadura production is concentrated in rural areas, where traditional methods of sugarcane juice extraction and concentration are employed. Rapadura is widely used in Brazilian cuisine and is valued for its nutritional properties and distinctive flavor (Obando, 2010).

The production and international commercialization of panela face several challenges, including quality standardization, adaptation to international regulations, and competition with other sweeteners. However, the growing demand for natural and organic products presents significant opportunities to expand the panela market and improve the incomes of rural producers.

General market of Panela.

Panela has played a significant role in both local and global economies, driving growth in rural and urban communities. In terms of global production, India leads with 86% of the world's panela output, followed by Colombia, which holds second place with 13.9% of global production (García, Rivera & Rivera, 2019). Other producing countries include China, Pakistan, and several Latin American nations such as Peru, Brazil, and Mexico, though their production levels are significantly lower, accounting for no more than 0.01% of global output.

In Colombia, panela represents the second most important rural agribusiness, after coffee, generating over 285,000 direct jobs and approximately 570,000 indirect jobs. Sugarcane for panela production is cultivated in 27 departments, involving more than 170 municipalities that depend directly on this economic activity (Ministry of Agriculture and Rural Development, 2015). This production is essential for the rural economy, contributing significantly to the country's agricultural Gross Domestic Product (GDP).

Panela production in Colombia not only meets domestic demand but has also been

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

oriented toward exports, particularly to markets that value organic and natural products. This trend is supported by government policies that incentivize the formalization and export of panela, thereby improving market opportunities for local producers (La Opinión, 2019).

In terms of competition, Colombian panela faces significant challenges due to competition from other producing countries such as Brazil and Mexico, which are also developing their panela markets. Nevertheless, the quality and nutritional properties of Colombian panela provide a competitive advantage, especially in markets seeking healthy and sustainable products.

In recent years, the Colombian economy has shown signs of slowdown, influenced by external volatility and a decline in domestic demand. Despite this, GDP growth of 1.5% is projected for 2024, driven by private consumption and fixed investment (de Política Monetaria & de Modelos, 2024). This broader economic context directly impacts the panela sector, which must adapt to changing market conditions to maintain its competitiveness and sustainability (Ballesteros Escobar & Palacio Archer, 2021).

Panela consumption in Colombia has steadily increased, driven by its nutritional value and role as a traditional food. This growth in domestic demand, coupled with government policies promoting product formalization and export, creates a favorable environment for the development of the panela sector (Restrepo & Flórez, 2017). It is essential to adopt modernization and marketing strategies that facilitate the exploitation of these opportunities and strengthen the sector's competitiveness at both national and international levels.

At the local level, the municipality of Convención stands out as an important panela production center, though processing methods date back more than 30 years, resulting in low productivity and resource waste (López Sánchez et al., 2019). Modernizing these techniques and improving infrastructure are crucial to enhancing product efficiency and quality, as well as complying with current health and environmental standards.

Analysis of the economic performance and challenges of the panaleta sector in the Catatumbo region

The general objective of this article is to analyze the economic performance and challenges of the panaleta sector in the Catatumbo region of Colombia, identifying development opportunities and strategies for strengthening the sector to contribute to sustainable rural development. The specific objectives include characterizing the predominant production techniques in the sector, highlighting limitations and opportunities for technological modernization; evaluating the impact of public policies and associativity on the sustainability and competitiveness of the panaleta sector in the region; and proposing strategies for quality standardization and the creation of a collective brand to differentiate panaleta from Catatumbo, enhancing its competitiveness in external markets.

METHODOLOGY

This study is based on a systematic literature review to analyze the economic performance and challenges of the panaleta sector in the Catatumbo region, Colombia (Barrientos-Monsalve, Sotelo-Barrios & Hoyos-Patiño, 2023). The methodology was designed to ensure a comprehensive collection and rigorous analysis of existing literature, providing a solid foundation for developing strategies to strengthen the panaleta sector in this region.

An exhaustive search of the literature was conducted in academic databases such as Scopus, Web of Science, Google Scholar, AGRIS, and CAB Abstracts. Keywords included combinations of terms such as "panaleta production," "rural development Catatumbo," "Colombian panaleta economy," and "agricultural competitiveness" (Barrientos Monsalve, Velásquez-Carrascal, & Hoyos-Patiño, 2021).

Inclusion Criteria:

- Publications in Spanish and English, published between 2010 and 2023.
- Studies related to panaleta production, rural development in Catatumbo, or economic analyses of the agricultural sector in Colombia.
- Peer-reviewed articles, government reports, and relevant research theses on the panaleta sector.

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Exclusion Criteria:

Studies not specifically focused on the Colombian context or lacking empirical data or relevant analyses for panela production in Catatumbo were excluded.

The study selection process was conducted in two stages. First, the titles and abstracts of identified studies were reviewed for a preliminary selection based on relevance to the article's central theme. Subsequently, preselected studies were read in full to assess their relevance and quality. Only those meeting the established criteria were included in the review. Reference management software, Zotero, was used to organize studies and avoid duplicates (Barrientos Monsalve et al., 2021).

Relevant data were extracted from each study, including study objectives, context, methodology, key findings, and recommendations. This information was organized into thematic matrices to facilitate analysis. A critical analysis of the studies allowed for the identification of strengths and weaknesses in methodological approaches and the evaluation of gaps in the existing literature. Subsequently, the information was synthesized around key themes such as the productive characteristics of the panela sector, economic challenges, market opportunities, and development strategies.

To ensure the validity of the results, source triangulation was employed by comparing findings from different studies and contrasting quantitative and qualitative data. Additionally, the article's methodology and results underwent a peer-review process, where field experts provided feedback to enhance the quality of the work (Dulcey Nieves & Coronel Montaguth, 2014; Barrientos Monsalve et al., 2021).

RESULTS AND DISCUSSION

This section presents a detailed analysis of the literature used in this study, aiming to evaluate the diversity and relevance of the consulted sources. The analysis focuses on two key aspects: the temporal distribution of publications and the typology

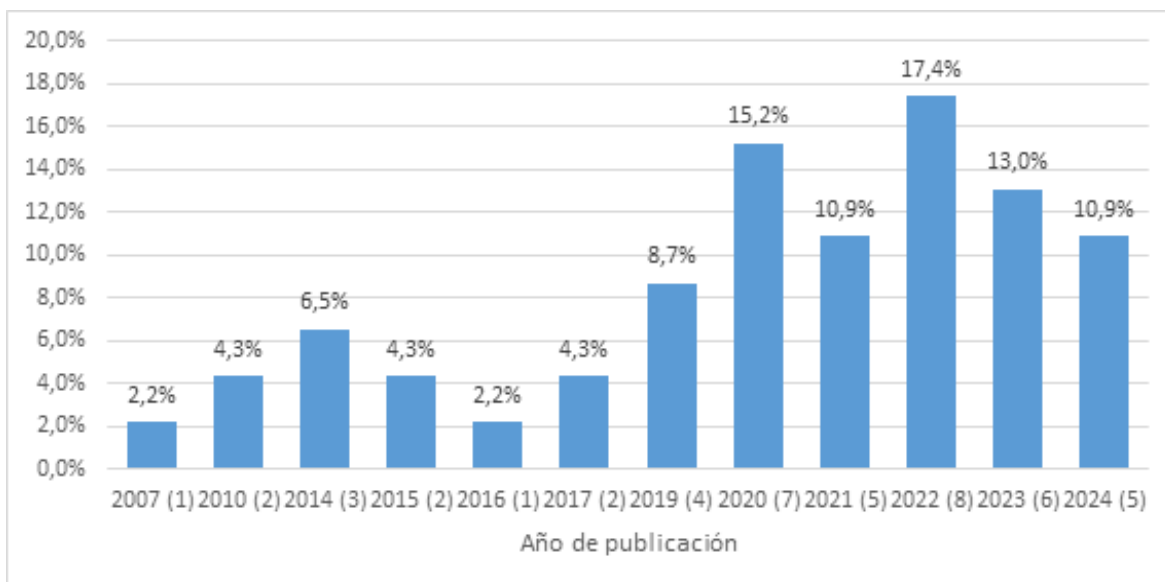
Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

of cited sources. The first table examines the relationship of publications by year, identifying trends in academic and documentary production related to the panela sector in Colombia (Table 1). The second table classifies references by type, distinguishing between theses, academic articles, government documents, and organizational reports, providing a comprehensive view of the information bases used in this work (Table 2). These analyses are fundamental for understanding the rigor and breadth of the theoretical framework supporting the research.

The graph shows an increasing trend in academic and report production related to the panela sector from 2007 to 2024, with a notable rise starting in 2019. Peaks in 2020 (15.2%) and 2022 (17.4%) stand out as years of intense research activity, suggesting heightened interest in the topic during these periods. This increase may be linked to recent developments in agroindustrial technologies, government policies focused on the sector, and increased funding for research in this area. The continuity in publication numbers through 2024 reflects the enduring relevance of the topic, indicating that the panela sector remains a crucial field of interest for academia and public policy in Colombia.

Table 1.

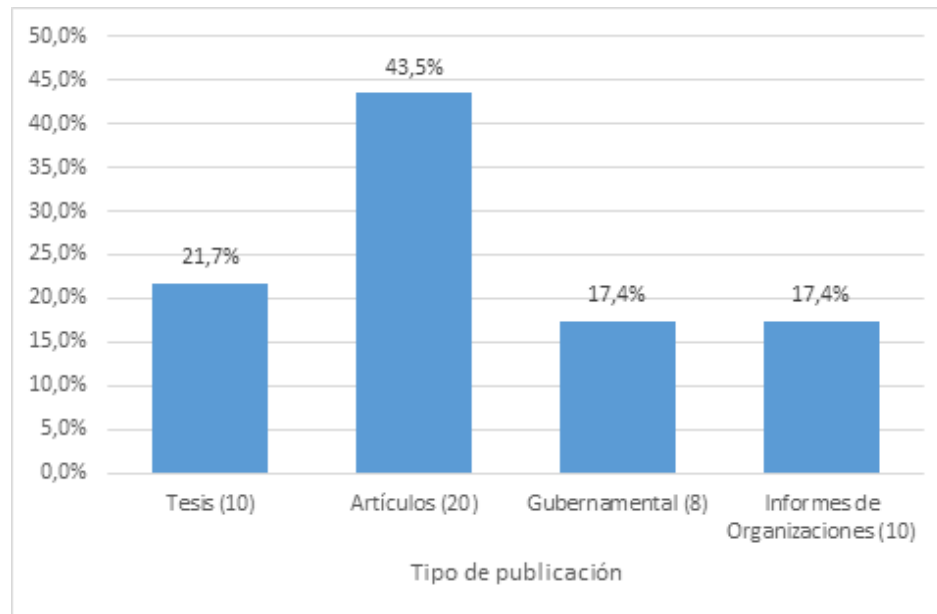
Relationship of publications by year. Own elaboration.



Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Table 2.

Type of publication analyzed. Own elaboration



The graph shows the distribution of publication types used in the article, highlighting that the majority are academic articles, representing 43.5% of the total. Theses also have a significant presence, constituting 21.7% of the references, reflecting a solid base of academic research in the area. Government sources and organizational reports each account for 17.4% of the total, underscoring the importance of these sources for contextualizing the panela sector within public policies and development initiatives. This distribution demonstrates a balanced approach in the use of diverse information sources, combining academic research with official documents and sectoral studies to provide a comprehensive analysis.

Context of the Panela sector in Catatumbo

The panela sector in the Catatumbo region, particularly in municipalities such as Convención, has become a cornerstone of the local economy. This crop not only represents a significant source of income for thousands of families but also serves as an engine for rural development in a region historically affected by armed

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

conflict. Panela production, a derivative of sugarcane, has emerged as a viable and sustainable economic alternative to less legal activities, such as coca cultivation (Dulcey Nieves & Coronel Montaguth, 2014; Minagricultura, 2017).

In this regard, the panela agroindustry in Catatumbo has demonstrated notable resilience and adaptability, enabling local producers to not only meet domestic demand but also explore international markets. This sector is considered the primary generator of employment in municipalities like Convención, where more than 350 families depend directly on panela production (Bastos et al., 2019). Associativity, promoted through cooperatives such as COINCAPRO, is key to improving production and commercial conditions for panela producers, facilitating access to technical assistance and the adoption of better agricultural practices (Bastos Osorio et al., 2020).

Challenges and opportunities in panela production

Despite significant progress, the panela sector in Catatumbo faces several challenges that limit its growth potential. One of the most critical issues is the lack of standardization in production processes and the absence of quality certifications, which hinders penetration into more demanding international markets (Fedepanela, 2009; Bastos Osorio et al., 2020). The trapiches, the basic infrastructure for transforming sugarcane into panela, mostly operate at less than 70% of their installed capacity, indicating considerable room for improvement in terms of efficiency and productivity (Minagricultura, 2016).

Additionally, the volatility of panela prices, influenced by factors such as oversupply and competition with imported products from Venezuela, has negatively affected the profitability of small producers (Minagricultura, 2017). However, significant opportunities exist for sector development, particularly if a distinctive brand for Catatumbo panela can be established in national and international markets. The growing global demand for organic and natural products presents a window of opportunity to position Catatumbo panela as a premium product, provided the necessary quality standards are met (Bastos Osorio et al., 2020).

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Strategies for strengthening the sector

To strengthen the panela sector in Catatumbo, it is essential to implement a series of strategies addressing both production challenges and commercial opportunities. First, the standardization of production processes should be promoted through training and technical assistance, ensuring producers comply with quality regulations required by international markets (Dulcey Nieves & Coronel Montagu-th, 2014). Likewise, fostering associativity among producers is crucial to facilitate access to resources and participation in more competitive markets.

Regarding commercialization, the development of a collective brand representing Catatumbo panela could be a decisive step to improve its market positioning. This brand should be backed by quality certifications ensuring the product's authenticity and nutritional value. Finally, public policies must support the modernization of production infrastructure, incentivizing investment in technology to enhance efficiency and reduce production costs (Minagricultura, 2017).

The success of these strategies will largely depend on collaboration among the various stakeholders involved, including producers, cooperatives, local governments, and international organizations. Only through coordinated efforts can current obstacles be overcome, and the agroindustrial potential of panela in Catatumbo fully realized.

History of the panela sector at the local level

In the Catatumbo region, panela production is an economically and culturally significant activity (Toro, 2022). Since colonial times, this region has developed a strong tradition in panela production, characterized by artisanal techniques and extensive family involvement. The municipalities of San Calixto, Teorema, and Convención stand out as the main sugarcane production centers for panela, driving the local economy and generating employment for a large number of rural families (Manosalva, 2022).

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

At the local level, panela production in Ocaña has evolved significantly, though it still faces major challenges related to the modernization of techniques and production infrastructure. According to Barbosa Sandoval (2015), the infrastructure used for panela production in the region is outdated and obsolete, resulting in low productivity and high levels of resource waste. This scenario underscores the urgent need to modernize processes and improve technological conditions to enhance product efficiency and quality.

Initially, panela produced in the region was distributed through intermediaries in the province of Ocaña and also marketed on the Atlantic coast, this distribution, while effective, limited local producers' opportunities to access broader and more competitive markets (Pérez Lobo & Rojas Contreras, 2020). Currently, the growing interest in organic and natural products presents an opportunity for Ocaña panela producers to position themselves in national and international markets, capitalizing on the trend toward healthier food consumption.

The most direct competition for Catatumbo panela producers comes from regions such as Boyacá and Santander, where high-quality panelas with lower chemical content are produced, making them attractive in demanding markets (Mogrovejo Andrade *et al.*, 2022). However, Catatumbo panela has the potential to compete favorably if improvements in production processes are implemented and sustainable practices are adopted to highlight its nutritional and natural value (Hoyos-Patiño, Velásquez & Hernández Villamizar, 2020). The history of the panela sector in the region reflects a combination of tradition and challenges, with clear potential for growth and sustainable development through modernization and effective marketing strategies.

Productive characteristics of the panela sector in Catatumbo

The panela sector in the Catatumbo region, particularly in municipalities like Convención, has evolved considerably in recent decades, becoming a key component of the local economy. This sector is characterized by the artisanal and semi-industrial production of panela, a sugarcane-derived product cultivated on more than 2,500 hectares of land (Dulcey Nieves & Coronel Montaguth, 2014). Panela production in

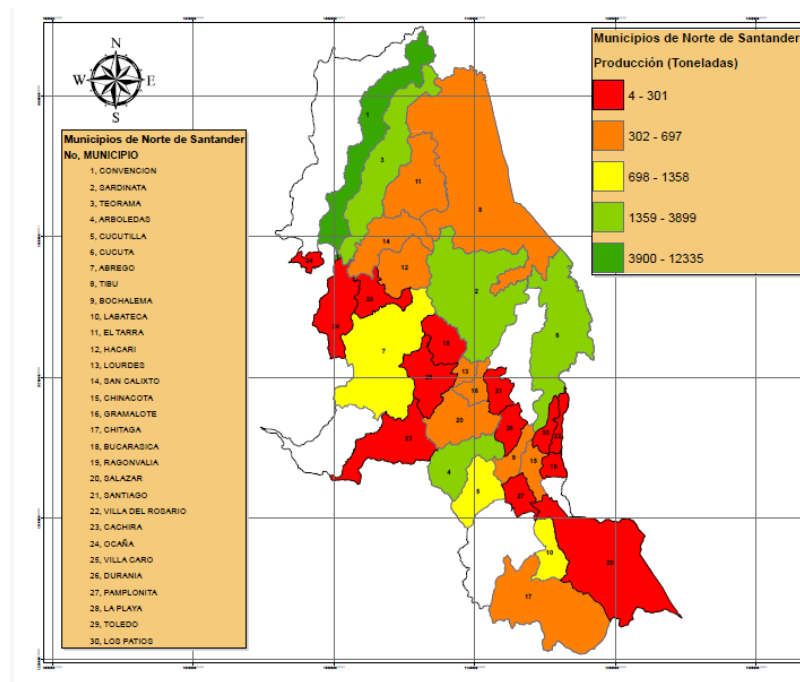
Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

this region is led by small and medium producers (Figure 1), grouped into cooperatives such as COOINCAPRO, which facilitate commercialization and access to technical services for farmers (Bastos Osorio, Mogrovejo Andrade, & García Torres, 2020).

Figure 1: PANELA PRODUCTION IN NORTE DE SANTANDER – 2018 (Tons)

Figure 1.

Map of panela production by municipalities in Norte de Santander (2018). Adapted from the National Federation of Panela Producers, Panela Information System (S.I.P.A), 2018.



The presented map illustrates the distribution of panela production in the municipalities of Norte de Santander during 2018. Production is concentrated primarily in the municipalities of Convención, Sardinata, and Teorama, which lead in volume with over 3,900 tons annually. These municipalities benefit from better agroecological conditions and access to infrastructure, driving their productivity. In contrast,

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

municipalities such as Bucarasica and Chitagá show significantly lower production due to infrastructure and technological limitations. This disparity highlights the need for strategies promoting modernization and strengthening productive capacity in less developed areas, fostering equitable growth of the panela sector across the region.

One of the distinctive characteristics of the panela sector in Catatumbo is its high reliance on traditional cultivation and processing techniques, which, while ensuring artisanal product quality, limit mass production capacity and competitiveness in international markets (Minagricultura, 2017). Most trapiches operate at less than 70% of their installed capacity, suggesting considerable room to increase efficiency and production (Bastos *et al.*, 2019). This aspect is critical, as growing demand in external markets requires consistent volumes and standardized quality, two areas where the Catatumbo panela sector must improve substantially.

Sugarcane cultivation in the region benefits from unique agroecological conditions, such as fertile soils and a favorable climate, yielding over 7 tons per hectare, slightly above the departmental average but below the national yield (Dulcey Nieves & Coronel Montaguth, 2014). However, the sector faces significant challenges, including competition with illicit crops and the lack of technological renewal in trapiches, affecting both productivity and business sustainability.

The panela market in Catatumbo has traditionally focused on domestic consumption, with minimal participation in exports. This is partly due to the lack of standardization and certifications, which are essential requirements for competing in international markets (Bastos Osorio *et al.*, 2020). Nevertheless, with the growing global demand for natural and organic products, the Catatumbo panela sector has a unique opportunity to expand and position its product in market niches that value authenticity and artisanal quality.

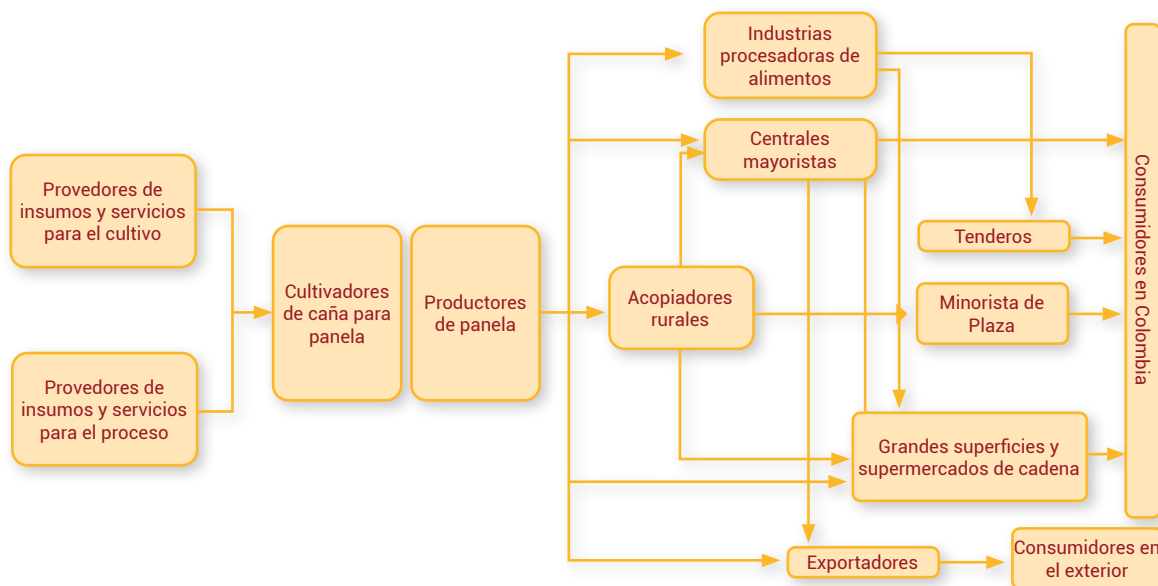
Structure of the panela value chain

The diagram highlights the interconnections among the different actors in the production process, from input and service providers to end consumers, both at national and international level. The value chain begins with sugarcane growers and panela producers, who are fundamental in transforming the crop into the final product. Next, rural collectors and other intermediaries facilitate the transit of panela

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

through various commercial channels, including wholesale centers, shopkeepers, supermarkets, and exporters. This structure underscores the complexity and importance of coordination among all actors to ensure panela reaches consumers in optimal condition and with the added value each stage of the process provides (Figure 2).

Figure 2.
Structure of the panela value chain.



Source: FEDEPANELA (2019).

The panela value chain in Colombia consists of several interrelated actors who play key roles in the production, transformation, commercialization, and distribution of the product. According to Serna Rincón & Chaparro Rojas (2020), these actors are:

1. Input and service suppliers: ECompanies and personnel dedicated to the production and supply of agricultural inputs such as seeds, fertilizers, pesticides, and irrigation equipment. Also included are providers of machinery and equipment for sugarcane milling and processing.

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

2. Sugarcane producers: Farmers who cultivate sugarcane using traditional or modern techniques. These producers are responsible for harvesting and transporting sugarcane to trapiches for processing.
3. Trapiches: Establishments where sugarcane is milled, extracted, evaporated, and concentrated to produce panela. Trapiches can be small, medium, or large, varying in terms of technology and efficiency.
4. Distributors and marketers: Companies and cooperatives responsible for distributing and selling panela in local markets. These entities play a crucial role in connecting producers with final consumers.
5. Consumers: The final market includes both domestic and international consumers who value panela for its nutritional properties and use in a variety of food products.

This organization of the value chain emphasizes the relevance of each stage in the production and commercialization of panela, highlighting the need for coordination and cooperation among diverse actors to enhance the sector's competitiveness and sustainability.

Benefits granted to panela producers

En Colombia, los productores de panela han recibido diversos incentivos y apoyos para fortalecer su actividad productiva y mejorar su competitividad. Estos beneficios se han implementado a través de políticas gubernamentales y programas específicos diseñados para atender las necesidades del sector panelero.

Fiscal incentives and assistance programs: The Panela Law (Congreso de Colombia, 2019), enacted before the COVID-19 pandemic, establishes fiscal incentives and technical assistance programs to expand the demand for panela and its derivatives. This law seeks to diversify panela production and commercialization, promoting innovation in the sector. Small and medium producers can benefit from these incentives, which include the possibility of producing alcohols for human consumption, thereby diversifying income opportunities (Olvera Garcia & Quintana

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Macias, 2021).

Export support: Panela production is promoted through various initiatives. For example, the importance of complying with quality and safety standards and understanding consumer preferences in international markets has been emphasized. The National Federation of Panela Producers (Fedepanela) and companies like BLACKMILL have worked together to strengthen the presence of Colombian panela in markets such as the United States, Europe, and Asia, promoting its unique quality and flavor (Cidecolombia, 2023).

Events and fairs: Events like EXPOPANELA 2023 provide a platform for panela producers to showcase their advancements and products at national and international level. This event, organized by FEDEPANELA, allows producers, marketers, and public and private entities to gather, exchange experiences, learn about new technologies, and explore commercial opportunities. EXPOPANELA highlights the importance of panela in the Colombian economy and its potential to contribute to the country's sustainable development (Expopanela, 2023).

Modernization and training programs: The FAO and other international organizations have supported projects to modernize the panela sector, such as the Agro-Food Supply System of Antioquia (SABA). These programs aim to strengthen agricultural chains and expand commercialization channels. The FAO has promoted the participation of Colombian panela in global initiatives, highlighting its unique qualities and special characteristics that can contribute to more efficient and sustainable agri-food systems (Correa, 2021).

Tax incentives for the acquisition, marketing, and export of panela

In Colombia, panela producers have received various fiscal incentives and tax benefits designed to support the acquisition, marketing, and export of this product. These measures aim to improve the competitiveness of the panela sector and promote its growth in both domestic and international markets.

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Exemptions and tax deductions: The Colombian government has implemented a series of tax exemptions and deductions for panela producers. Among the most notable benefits is a ten-year income tax exemption for producers dedicated to panela production, provided they meet certain requirements established by current regulations (Soto, 2022). Additionally, discounts on value-added tax (VAT) are provided for the purchase of inputs and machinery necessary for panela production, facilitating the modernization of production techniques and infrastructure improvements.

Export incentives: The Panela Promotion Fund (El Fondo de Fomento Panelero) is a key tool for boosting panela exports. This fund provides resources to support producers in promoting and commercializing panela in international markets. Producers who meet adequate labeling and traceability requirements can access these funds, enabling them to improve product presentation and comply with quality and safety standards demanded by international markets (Cidecolombia, 2023).

Support and technical assistance programs: In addition to fiscal incentives, the government and international organizations have developed support and technical assistance programs for panela producers. For example, the FAO has collaborated with local entities to offer training and technical assistance in modernizing production processes, promoting sustainable and efficient practices that enhance product quality and reduce production costs (Correa, 2021).

Panela Law: Law 2005 of 2019, also known as the Panela Law, establishes a series of guidelines to encourage innovation and growth in the panela sector. This law includes incentives for producing alcohols from panela, opening new market opportunities for small and medium producers. Additionally, the law promotes national consumption campaigns and supports the formalization of producers, facilitating their access to government benefits and support programs (Congreso de Colombia, 2019).

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Plans and programs to formalize technology

In Colombia, the modernization and technification of the panela sector have been promoted through a series of projects and strategic alliances. AGROSAVIA has led initiatives including self-propelled monocable transport systems, production of selected sugarcane seeds, and hybrid evaporation models for panela production (AGROSAVIA, 2024). These technologies aim to improve the energy and environmental efficiency of panela furnaces, optimize the management of binding species used in sugarcane juice clarification, and provide more sustainable and profitable methods for producers (Gómez Espinosa, 2022).

Additionally, FEDEPANELA has established alliances with entities such as Husqvarna to facilitate access to machinery and equipment at competitive rates, benefiting small and medium panela producers. These alliances seek to optimize production times and costs, thereby improving sector profitability (Casanova Ortiz, 2022). Technification also includes training and update sessions that enable producers to learn about and adopt new technologies, strengthening the productive chain and contributing to the sector's sustainable development (Rodríguez, *et al.* (2020).

Institutional acquisition of panela

The institutional acquisition of panela is promoted through programs that incentivize the consumption of local products in public entities. These programs ensure that panela is included in the offerings of government cafeterias and restaurants, as well as in food supply contracts for these institutions. This approach not only guarantees a stable market for local producers but also fosters the consumption of natural and organic products, strengthening the rural economy (Casanova Ortiz, 2022).

Furthermore, institutional support extends through policies promoting panela purchases in educational institutions and hospitals, creating a steady and significant demand for producers. These programs contribute to the economic sustainability of the panela sector and ensure that the benefits of local production are widely

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

distributed, improving the quality of life in rural communities (Cidecolombia, 2023).

Gains for peasants, artisans, and entrepreneurs

Support programs for peasants, artisans, and entrepreneurs in the panela sector include fiscal incentives and facilities for business formalization. The Panela Law offers benefits such as a ten-year income tax exemption and access to credit at preferential rates. These incentives are designed to enhance the economic viability of small and medium panela enterprises, facilitating their growth and sustainable development (Soto, 2022; Velásquez-Carrascal *et al.*, 2020).

Additionally, the formalization of producers enables them to access broader markets and obtain better prices for their products. The creation of associations and cooperatives is also promoted as a strategy to strengthen producers' bargaining power and improve their access to resources and services. These initiatives not only increase producers' incomes but also contribute to social cohesion and the economic development of rural communities (Olvera Garcia & Quintana Macias, 2021).

Government and municipal support

The Colombian government, through the Ministry of Agriculture and Rural Development and other entities, has implemented technical and financial assistance programs for panela producers. These supports include subsidies for the purchase of inputs and machinery, as well as training in good agricultural practices and sustainable management. Local governments also play a crucial role by promoting producer formalization and supporting the creation of associations and cooperatives (Polo-Murcia *et al.*, 2022).

Additionally, municipalities have developed specific programs to improve production infrastructure, such as the construction of collection and processing centers. These local efforts are complemented by national programs aimed at enhancing the competitiveness of the panela sector, ensuring small producers can access markets under favorable and sustainable conditions (Rodríguez *et al.*, 2020).

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Stimulus for panela-related tourism

Rural tourism related to panela production is incentivized through the creation of tourist routes and immersive experiences. Programs like “La Ruta de la Panela” (The Panela Route) allow tourists to visit trapiches and participate in the panela production process. This type of tourism not only generates additional income for producers but also promotes the region's cultural and gastronomic heritage, attracting national and international visitors (Polo-Murcia *et al.*, 2022).

These tourism initiatives include the promotion of panela-related events and festivals, where tourists can learn about the history and culture of panela production. Additionally, rural accommodations offering authentic countryside experiences have been developed, contributing to the economic and sustainable development of rural communities (Hoyos-Patiño, Hernández-Villamizar & Velásquez-Carrascal, 2019).

Strategy for better development of the panela sector

To improve the development of the panela sector, strategies focused on technological modernization, producer formalization, and market expansion have been implemented. The adoption of advanced technologies and training in sustainable practices are fundamental to increasing productivity and panela quality. These strategies include the implementation of new production methods and the promotion of more efficient and eco-friendly inputs (Gómez Espinosa, 2022; Velásquez Carrascal, B. L., *et al.*, 2020).

Furthermore, promoting panela consumption at national and international levels, along with the creation of new derived products, is key to diversifying the market and ensuring sector sustainability. Marketing campaigns and commercial alliances aim to position Colombian panela in international markets, highlighting its nutritional properties and natural origin, which can open new business opportunities and improve producer incomes (Cidecolombia, 2023).

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Economic value for peasant families

Panela production constitutes one of the primary sources of income for thousands of peasant families in Colombia. This sector generates direct and indirect employment, providing economic stability and improving the quality of life in rural areas. Support policies and rural development programs have been crucial to strengthening this economic activity, ensuring benefits reach the most needy communities (Soto, 2022; Moreno & García, 2020).

Additionally, the formalization and technification of the panela sector have enabled small producers to increase their incomes and access more competitive markets. Government support and international cooperation initiatives have facilitated the adoption of new technologies and sustainable practices, improving production efficiency and profitability, directly benefiting peasant families (Gómez Espinosa, 2022).

Potential of AI in Sugarcane Production

Artificial intelligence (AI) is revolutionizing sugarcane production, offering significant improvements in efficiency, sustainability, and profitability for this agricultural sector (Patiño, Carrascal, Bautista & Díaz, 2023). One of the most notable applications of AI is in yield and sugar content prediction using deep learning models. These models utilize vast amounts of data, including meteorological information, remote sensor data, agronomic attributes, and historical records, to provide accurate and detailed predictions that enable producers to make informed decisions and optimize their operations. For instance, GAMAYA has developed AI models that can predict sugarcane yield and sugar content with up to 98% accuracy, leading to significant improvements in plantation management and productivity (GAMAYA, 2024).

In addition to yield prediction, AI is being used to monitor and assess sugarcane crop health. Projects such as those developed by CSIRO and the University of Wollongong in partnership with Vietnamese tech company VIGREEN have implemen-

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

ted AI-driven aerial monitoring systems that detect plant health issues, such as nutritional stress, water stress, and foliar diseases. These systems enable farmers to receive real-time data via mobile applications, facilitating quick and effective decision-making to protect their crops and ensure productivity (Pachón & Fernández, 2024). The integration of AI and automation in harvesting and crop management allows farmers to optimize their operations, improving efficiency and reducing operational costs. This is achieved through the use of drones and sensors that collect precise data on crop and soil conditions, enabling timely and accurate adjustments to agricultural practices.

The application of AI in sugarcane production is also driving environmental sustainability. AI technologies enable more precise resource management, such as efficient water and fertilizer use, reducing the environmental impact of agricultural production. Additionally, AI is being used to analyze soil organic content and verify carbon removal programs, contributing to the fight against climate change. These innovations not only enhance producer profitability but also promote more sustainable and responsible agricultural practices (GAMAYA, 2024).

Below, as presented in Table 3, is a synthesis of the main contributions derived from the results of this study. This table summarizes the key aspects identified in the analysis of the panela sector in Catatumbo, highlighting technological limitations, the impact of public policies and associativity, proposed strategies to improve competitiveness in external markets, and the importance of a comprehensive vision of sustainable rural development. These contributions provide a solid foundation for formulating specific recommendations and guide future interventions in the sector, aiming to promote its long-term growth and sustainability.

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

Table 3.
Contributions derived from the research results.

Aportación	Descripción	Impacto Esperado	Recomendaciones
Diagnóstico de las Limitaciones y Potencialidades Tecnológicas	Se realizó un diagnóstico detallado de las técnicas productivas utilizadas en el sector panelero del Catatumbo, identificando tanto las limitaciones tecnológicas actuales como las potencialidades para su modernización.	Mejorar la eficiencia productiva en un 20% mediante la adopción de tecnologías modernas.	Invertir en capacitación y acceso a tecnologías avanzadas.
Impacto de las Políticas Públicas y la Asociatividad en el Sector	Los resultados revelan que las políticas públicas implementadas han tenido un impacto desigual en el sector panelero. Se observa que la asociatividad juega un papel crucial en fortalecer las capacidades de los productores y en mejorar el acceso a mercados.	Incrementar la competitividad del sector panelero en un 15% a través de políticas más inclusivas.	Promover políticas que fortalezcan la asociatividad en la región.
Propuesta de Estrategias para la Competitividad en Mercados Externos	Formulación de estrategias dirigidas a la estandarización de la calidad y la creación de una marca colectiva para la panela del Catatumbo, con el fin de mejorar su competitividad en mercados nacionales e internacionales.	Aumentar las exportaciones de panela en un 10% dentro de los próximos cinco años.	Realizar estudios de mercado para la creación de una marca colectiva.
Visión Integral de Desarrollo Rural Sostenible	El artículo aporta una visión integral del desarrollo rural sostenible en el contexto del sector panelero, considerando los impactos productivos, económicos, sociales y ambientales.	Desarrollar un modelo de producción panelera sostenible en la región.	Fomentar incentivos para la adopción de prácticas sostenibles.

Source: Own elaboration.

Analysis of the economic performance and challenges of the panela sector in the Catatumbo region

CONCLUSIONS

The analysis of the economic performance and challenges of the panela sector in the Catatumbo region reveals a series of key conclusions essential for understanding the sector's current dynamics and future development opportunities.

Regarding the need for technological modernization, it was identified that the predominant production techniques in the region are largely traditional, limiting the sector's competitiveness at national and international levels. Technological modernization is crucial to improving productive efficiency and ensuring the sector's long-term sustainability.

Concerning the impact of Public Policies and Associativity, it is evident that the public policies implemented to date have had a significant but uneven impact on sector development. Associativity emerges as a determining factor in strengthening the capacities of small and medium producers, improving their market access and enabling better adaptation to global market demands.

Regarding opportunities in external markets, the growing global demand for organic and natural products presents a unique opportunity for the Catatumbo panela sector. However, to fully capitalize on this opportunity, the creation of a collective brand differentiating Catatumbo panela for its quality and authenticity is essential, facilitating its positioning in international markets.

Regarding the comprehensive vision of sustainable rural development, the study underscores the importance of adopting an integrated approach to rural development that considers not only economic aspects but also social and environmental impacts. Developing a sustainable production model is essential to ensuring balanced growth of the panela sector, contributing to the well-being of local communities and environmental preservation.

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