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FRONTIERS OF PRODUCTION POSSIBILITIES FOR PHARMACEUTICAL PRODUCTS, MEDICINAL CHEMICAL SUBSTANCES, AND BOTANICAL PRODUCTS FOR PHARMACEUTICAL USE IN COLOMBIA

Yahilina Silveira Pérez[1*], José Ramón Sanabria Navarro[2], William Alejandro Niebles Núñez[3]

[1*]silveira@unisucre.edu.co Universidad de Sucre
[2]josesanabrian@correo.unicordoba.edu.co Universidad de Córdoba
[3]niebles@unisucre.edu.co Universidad de Sucre

***Corresponding Author:** Yahilina Silveira Pérez
*silveira@unisucre.edu.co Universidad de Sucre

Abstract
The pharmaceutical industry in Colombia has experienced significant growth in recent years, standing out for its potential in the production of pharmaceutical products, medicinal chemicals, and botanical products for pharmaceutical use. However, the dependence on the import of raw materials and finished products, along with technological and regulatory limitations, pose challenges for the optimization of the production possibilities frontiers in the sector. The objective of this study is to analyze the production possibilities frontiers of pharmaceutical products, medicinal chemicals, and botanical products for pharmaceutical use in Colombia, in order to identify areas for improvement and propose strategies to strengthen the national pharmaceutical industry. A quantitative approach was used to analyze production and efficiency data in the Colombian pharmaceutical industry. Data Envelopment Analysis (DEA) techniques were applied to assess the relative efficiency of production units and secondary data from official sources such as DANE and the Ministry of Health were used. The results of the study revealed that the pharmaceutical industry in Colombia faces significant challenges in terms of efficiency and production capacity. Areas for improvement in production technology, staff training, and regulatory harmonization were identified. In addition, innovation and the promotion of effective public policies were found to be key to strengthening the competitiveness of the sector. This study highlights the importance of optimizing the frontiers of production possibilities in the Colombian pharmaceutical industry to ensure access to quality medicines and strengthen the industry at the national level. The implementation of strategies that foster innovation, improve efficiency, and promote public policies that support the sustainable development of the pharmaceutical sector in Colombia is recommended.

Keywords: Frontiers of possibilities; production; pharmaceutical products; medicinal chemicals; botanical products for pharmaceutical use.

Introduction
The pharmaceutical industry in Colombia faces a panorama of great challenges and opportunities. Assessing the production possibilities frontiers (PPF) of pharmaceutical products, medicinal chemicals and botanical products for pharmaceutical use is essential to maximize the efficiency and

competitiveness of the sector. This assessment not only allows identifying limitations and areas for improvement, but also offers a roadmap for the sustainable development of the pharmaceutical industry in the country.

One of the most pressing problems in the Colombian pharmaceutical industry is the significant dependence on the import of raw materials and finished products. According to the Ministry of Commerce, Industry and Tourism (2020), approximately 70% of the inputs needed for the manufacture of medicines in Colombia are imported. This dependence creates vulnerabilities in the supply chain, especially in times of global crises, such as the COVID-19 pandemic, which has disrupted supply chains and highlighted the need to strengthen local production (Aristizábal, Ocampo, Quevedo et al., 2013).

Colombia is one of the world's megadiverse countries, with a rich biodiversity that offers significant potential for the production of botanical and medicinal products. Assessing FPPs in this context allows us to identify how to optimally exploit these natural resources to develop innovative and sustainable pharmaceutical products (Estrada, Álvarez, & Rentería, 2016). Colombia's biodiversity represents a unique opportunity to differentiate itself in the global market and promote innovation in the pharmaceutical industry (Forero & Rodríguez, 2011).

Optimizing FPPs in the Colombian pharmaceutical industry has important economic and social implications. Strengthening the national pharmaceutical industry through improved efficiency and competitiveness can generate employment, promote investment, and foster innovation in the sector (Villa & Saá, 2015). Furthermore, improving local production capacity contributes to the security of drug supply and reduces dependence on imports, which is crucial for the long-term sustainability of the sector (Arteaga et al., 2009).

Public policies and regulation play a crucial role in promoting efficiency and competitiveness in the pharmaceutical industry. The formulation of effective health and pharmaceutical policies is essential to ensure the quality, safety and accessibility of medicines (ARTECONA ET AL. (2020), 2017). Evaluating the FPP allows us to identify the regulatory and bureaucratic barriers that limit production and to propose improvements to facilitate the entry of new products into the market and the expansion of production capacities (Jemio and Sánchez, 2013).

Innovation and technological development are essential to improve the efficiency and competitiveness of the pharmaceutical industry, but pharmaceutical innovations can also have negative effects on the environment (Pemberthy, et al., 2020; Botero-Coy, et al., 2018; Alygizakis, et al., 2017). Promoting innovation in the pharmaceutical industry is key to strengthening the competitiveness of the sector and ensuring access to quality medicines for the population (Tai, 2017). Evaluating the FPP allows us to identify the areas in which investment in advanced technology and staff training are required to improve production processes and the development of new products (Rentería and Méndez, 2015).

Assessing the frontiers of production possibilities for pharmaceutical products, medicinal chemicals and botanical products for pharmaceutical use in Colombia is essential to ensure access to quality medicines, strengthen the competitiveness of the sector, promote innovation and contribute to the economic and social development of the country. This assessment provides valuable information to identify areas for improvement, implement effective strategies and promote a strong and sustainable pharmaceutical sector in Colombia.

Colombia has great potential in the production of pharmaceutical products, medicinal chemical substances, and botanical products for pharmaceutical use. The pharmaceutical product included development of generic and biosimilar drugs to meet local and regional demand, innovation in drug formulations and drug delivery technologies, strengthening the domestic pharmaceutical industry to reduce dependence on imports. Many medicinal chemical substances included leveraging Colombia's biodiversity for the extraction and synthesis of active principles, investment in R&D for the discovery and development of new molecules, improving production and purification processes to increase competitiveness. On the other hand, the botanical products for pharmaceutical use exploration and scientific validation of native medicinal plants with therapeutic potential, standardization and quality

control of plant-derived extracts and derivatives, development of phytopharmaceuticals and dietary supplements from natural resources and to capitalize on these frontiers, a comprehensive strategy is required, including: strengthening research and development infrastructure and capabilities, creating incentives and public policies that foster innovation and local production, collaboration between the public sector, academia, and industry to accelerate technology transfer and improving regulatory systems and quality assurance throughout the production process.

The pharmaceutical industry is a strategic sector at a global level, fundamental for public health and the economy of countries. In Colombia, this sector has shown significant growth in recent decades, driven by the growing demand for medicines and health products, as well as by the need to innovate and improve the quality of life of the population. The production of pharmaceutical products, medicinal chemicals and botanical products for pharmaceutical use represents a crucial opportunity for the economic and social development of the country.

Colombia has exceptional biodiversity, being one of the megadiverse countries in the world, which gives it a unique potential for the production of botanical and medicinal products (Rodríguez et al., 2016). This natural wealth, combined with an evolving regulatory framework and a growing research and development capacity, can position Colombia as a regional leader in the pharmaceutical industry. However, to achieve this potential, it is necessary to overcome several structural and operational challenges that limit the production capacity and competitiveness of the sector.

Despite the aforementioned potential, the pharmaceutical industry in Colombia faces multiple challenges that hinder its full realization. One of the main problems is the significant dependence on the import of raw materials and finished products. According to the Ministry of Commerce, Industry and Tourism (2020), Colombia imports approximately 70% of the inputs needed for the manufacture of medicines. This dependence creates vulnerabilities in the supply chain, especially in times of global crises such as the COVID-19 pandemic, which has disrupted supply chains and highlighted the need to strengthen local production.

In addition, the production infrastructure in Colombia still faces technological and capacity limitations. The lack of investment in advanced technology and the shortage of highly trained personnel limit the country's ability to compete with more developed markets. According to a report by the Chamber of the Pharmaceutical Industry of the ANDI (2021), the Colombian pharmaceutical industry needs significant modernization in terms of production technology and research and development processes.

Another major challenge is the regulatory framework. Although Colombia has made progress in regulating pharmaceutical products, there are still bureaucratic barriers and a lack of harmonization with international standards that hinder the entry of new products into the market and the expansion of production capacities. INVIMA (National Institute for the Surveillance of Medicines and Food) has worked to improve these processes, but greater efficiency and transparency are still required (INVIMA, 2019).

Given this context, the following problem question arises to guide this research: What are the production possibilities frontiers for pharmaceutical products, medicinal chemical substances and botanical products for pharmaceutical use in Colombia and how can they be optimized to strengthen the national pharmaceutical industry and guarantee access to quality medicines for the population?

General and Specific Objectives

General Objective:

Analyze the production possibilities frontiers for pharmaceutical products, medicinal chemical substances and botanical products for pharmaceutical use in Colombia and propose strategies for their optimization.

Specific Objectives:

Identify the existing production capacities in the Colombian pharmaceutical sector.

Evaluate the limitations and challenges in the production of pharmaceutical products in Colombia.

Design proposals and recommendations to improve the efficiency and competitiveness of the pharmaceutical industry in the country.

To address this problem, it is essential to review key concepts and theories that support pharmaceutical production and its optimization. The theory of production possibilities frontiers (PPF) provides a useful framework to analyze the efficiency and production capacity of a sector. This theory, derived from production economics, allows for the assessment of how available resources can be optimally used to maximize the production of goods and services (Varian, 2014).

In the context of the pharmaceutical industry, PPF can help identify the points at which current production deviates from optimal potential due to technological, regulatory, or human resource constraints. By mapping these boundaries and analyzing the gaps, specific strategies can be designed to close these gaps and improve the efficiency of the sector. The Production Possibilities Frontiers (PPF) theory is a fundamental concept in economics that describes the relationship between the production of different goods and services when resources are limited and used efficiently (Mankiw, 2014). In the context of the pharmaceutical industry, the PPF is applied to analyze the relationship between the production of pharmaceuticals, medicinal chemicals, and botanicals for pharmaceutical use in Colombia, considering the available resources and the technologies used in the production process.

The PPF shows the possible combinations of pharmaceutical products that an economy can produce given a specific level of resources and technology. By analyzing the production possibilities frontiers in the Colombian pharmaceutical industry, the maximum level of production achievable with the available resources can be identified and the efficiency in the allocation of these resources can be evaluated to maximize the production of medicines and related products.

Data Envelopment Analysis (DEA):

Data envelopment analysis (DEA) is a quantitative analysis technique used to assess the relative efficiency of a set of production units (Charnes, Cooper, & Rhodes, 1978). In the context of the pharmaceutical industry, DEA can be applied to compare the efficiency of different pharmaceutical companies in terms of the production of drugs and related products.

DEA allows for the identification of best practices and areas for improvement in pharmaceutical production by comparing the performance of production units in relation to a set of specific inputs and outputs. By using DEA in the analysis of production possibility frontiers in the Colombian pharmaceutical industry, the most efficient production units can be identified and benchmarks established for improving efficiency in the sector.

Innovation in the Pharmaceutical Industry

Innovation plays a crucial role in the pharmaceutical industry, allowing the development of new drugs, treatments and technologies that improve the health and well-being of the population. In the Colombian context, the promotion of innovation in the pharmaceutical industry is essential to strengthen the competitiveness of the sector and guarantee access to quality medicines for the population (Mayor's Office of Bogotá, 2020). Innovation in the pharmaceutical industry ranges from the research and development of new medicines to the implementation of advanced production technologies and the improvement of regulatory processes. When analyzing the frontiers of production possibilities in Colombia, it is important to consider the role of innovation in improving the efficiency and competitiveness of the sector, as well as in the generation of added value and the differentiation of products in the market.

Public Policies in Health and Pharmaceuticals

Public policies play a crucial role in the regulation and promotion of the pharmaceutical industry, guaranteeing the quality, safety and accessibility of medicines for the population (WHO, 2018). In Colombia, the formulation of effective public policies in health and pharmaceuticals is essential to address the structural and operational challenges faced by the pharmaceutical industry and to promote

sustainable development in the sector. Public health and pharmaceutical policies must address key aspects such as price regulation, promotion of competition, protection of intellectual property and promotion of local drug production. When analyzing the production possibilities frontiers in the Colombian pharmaceutical industry, it is essential to consider the impact of public policies on the efficiency and competitiveness of the sector, as well as on equitable access to medicines for the population.

Methods

Using the software called CO_FPP, based on the acronym of its main functions, is developed using Bootstrap, JavaScript, HTML5, and CSS3. Its specific objectives are:

1. Calculate the opportunity cost between the pre-established options by students of two productions, and specific points previously selected by the user.
2. Graph the production possibility frontiers, identifying the limits of inefficiency, unattainable, and productive efficiency.
3. Determine the shift of the production possibility frontier curve, generating whether there has been economic growth.

The production possibility frontier (PPF) is associated with the principle of scarcity or the limitation of resources. With this real-time software, students can quickly and effectively obtain the best combination or production option. The CO_FPP software is a study and simulation tool, feasible to use in a Virtual Learning Environment, as well as in a face-to-face setting, linking learning with communication technologies. One of the results that will be obtained is the opportunity cost (OC) for each option entered the system. The OC formula is used to calculate the cost of producing an additional unit of a good in terms of the amount of another good that must be given up. By default, in the software for ease of analysis, X= is the variable (production) that wins, Y= is the variable (production) that gives up. On the production possibility frontiers, this formula is expressed as follows:

Opportunity Cost (OC) = $\Delta Y / \Delta X$

Where:

ΔY represents the change in the production of good Y
ΔX represents the change in the production of good X

The opportunity cost measures the sacrifice that must be made in terms of the production of one good to obtain an additional unit of the other good. This cost is variable along the production possibility frontier, as the rate at which the goods can be exchanged changes as the production of one increase and the other decreases. The opportunity cost formula is important for understanding how businesses and countries should optimally allocate their resources to maximize production within their constraints.

Results

The production possibilities frontier (PPF) represents the different production combinations of two goods that an economy can achieve using all its resources efficiently (Table 1). In this context, each of these numerical values represents the opportunity cost of producing an additional unit of a good, in terms of the amount of the other good (Pharmaceuticals, medicinal chemicals, and botanicals for pharmaceutical use) that must be forgone. (Substances and chemical products).

Table 1. Calculation of Opportunity Costs

Option	Year	Pharmaceutical products, medicinal chemicals and botanical products for pharmaceutical use	Substances and chemicals product	Opportunity cost
A	2014	1079.1	1171.1	
B	2015	1129.6	1180.3	9.20
C	2016	1162.5	1174.6	5.70
D	2017	1147.9	1178.7	4.10
E	2018	1200	1200	21.29
F	2019	1197	1215.7	15.70
G	2020	1192	1172.5	43.20
H	2021	1263	1320.3	147.79
I	2022	1421	1434.1	113.79
J	2023	1364	1377	57.09

Source: Generated in CO-FPP Software

At the opportunity cost equal to 113.79, it means that to produce one more unit of the good in question, the economy would have to sacrifice 113.79 units of Substances and chemicals. Thus, the "best" opportunity cost would be the one that represents the least sacrifice in terms of the production of the other good. Among the values presented, the lowest opportunity cost would be 4.10, which would imply the lowest trade-off between the production of the two goods (Figure 1).

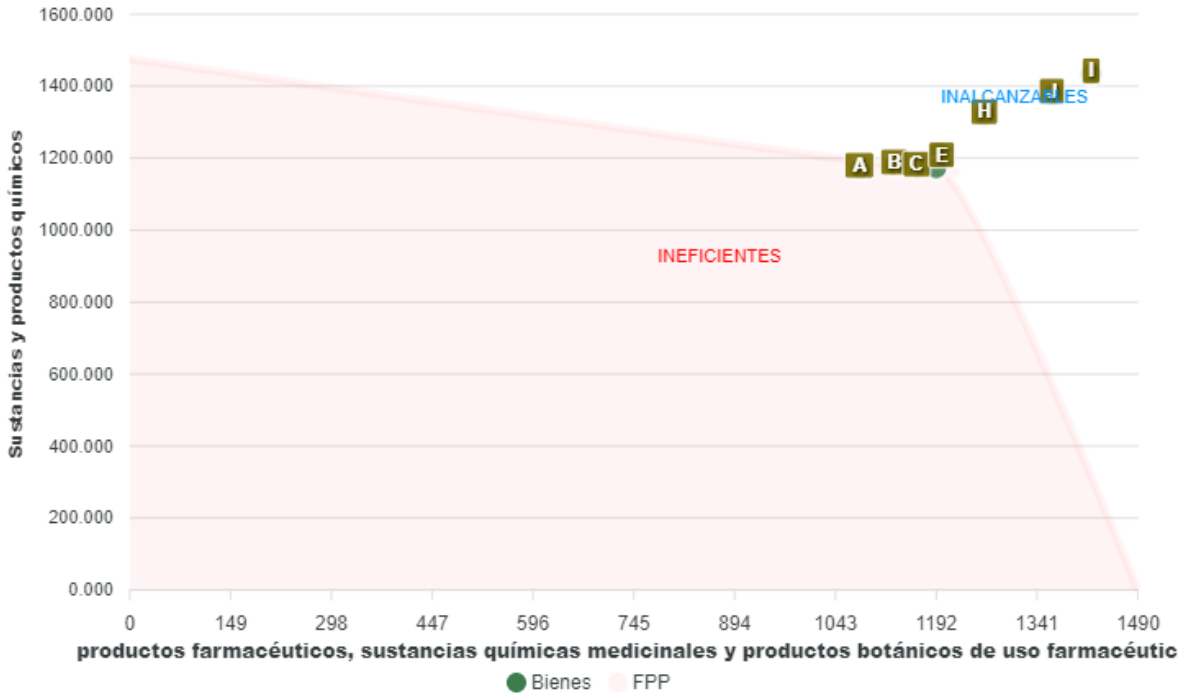

Figure 1. Production Possibilities Frontiers FPP1

It is perceived that the H, J, I productions are above the production possibility frontier, indicating that they are unattainable. These were pharmaceutical productions carried out above the country's productive capacity during the 2021-2023 period.

Shift of the Curve for the year 2024

It was possible to obtain a variation of 22.8 in X, and -5.2 in Y, based on DANE calculations with cut-off 2024 (Table 2). These values indicate a possible shift of the curve (Figure 2). Applying a shift

in the curve according to the projections for the end of 2024. Substances and chemicals show a decrease, so this will be the production to be sacrificed to raise pharmaceutical products, medicinal chemicals and botanical products for pharmaceutical use. The economy will need to shift its production away from substances and chemicals and reallocate those resources towards increasing the output of pharmaceutical-related products. This represents a shift along the PPF, where the economy can produce more of the desired pharmaceutical items, but at the cost of reduced production of other goods. The implication is that the country has made a strategic decision to prioritize the expansion of its pharmaceutical sector, even if it means contracting production in other areas of the economy.

Table 2 Calculation of Opportunity Costs with shift in the curve FPP2

	Pharmaceutical products, medicinal chemicals and botanical products for pharmaceutical use	**Substances and chemicals product**	**Opportunity cost**
A	1147.68	1081.89	
B	1201.39	1090.39	8.5
C	1236.38	1085.12	5.27
D	1220.85	1088.91	3.79
E	1276.26	1108.59	19.67
F	1273.07	1123.09	14.5
G	1267.76	1083.18	39.90
H	1343.27	1219.72	136.53
I	1511.31	1324.85	105.12
J	1450.69	1272.1	52.75

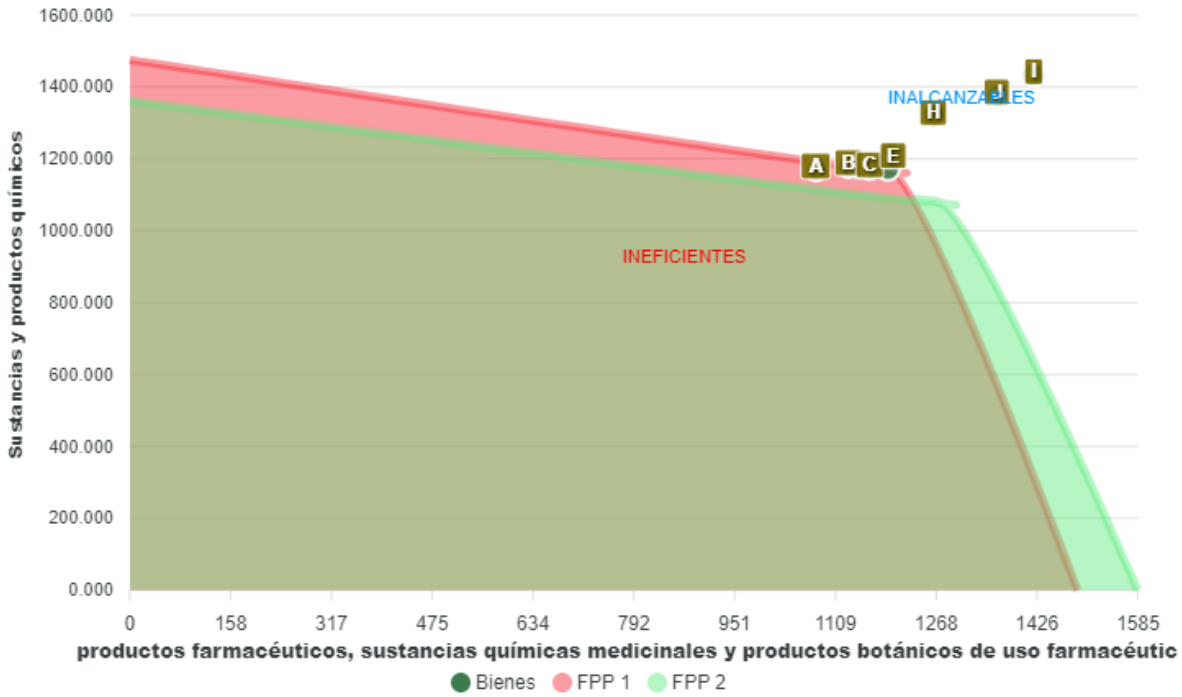

Figure 2. Shift of the Curve for the year 2024

Discussion

The pharmaceutical industry in Colombia presents a complex and multifaceted panorama, with diverse dynamics that impact its development and competitiveness. Below, the similarities and differences in key aspects such as drug production and distribution, regulation and surveillance, innovation and biodiversity, geographic concentration, competitiveness and productive efficiency, economic impact, and government policies are analyzed in greater detail.

Drug production in Colombia has shown sustained growth in recent years. The report of the Chamber of the Pharmaceutical Industry of the ANDI (2021) highlights that the adoption of advanced technologies and the diversification of the product portfolio have been determining factors in this growth. Similarly, the study by Arteaga et al. (2020) highlights the positive impact of enzymatic hydrolysis on the functional properties of pea proteins, illustrating how technological innovation can improve the quality of pharmaceutical products (Amagliani et al., 2020).

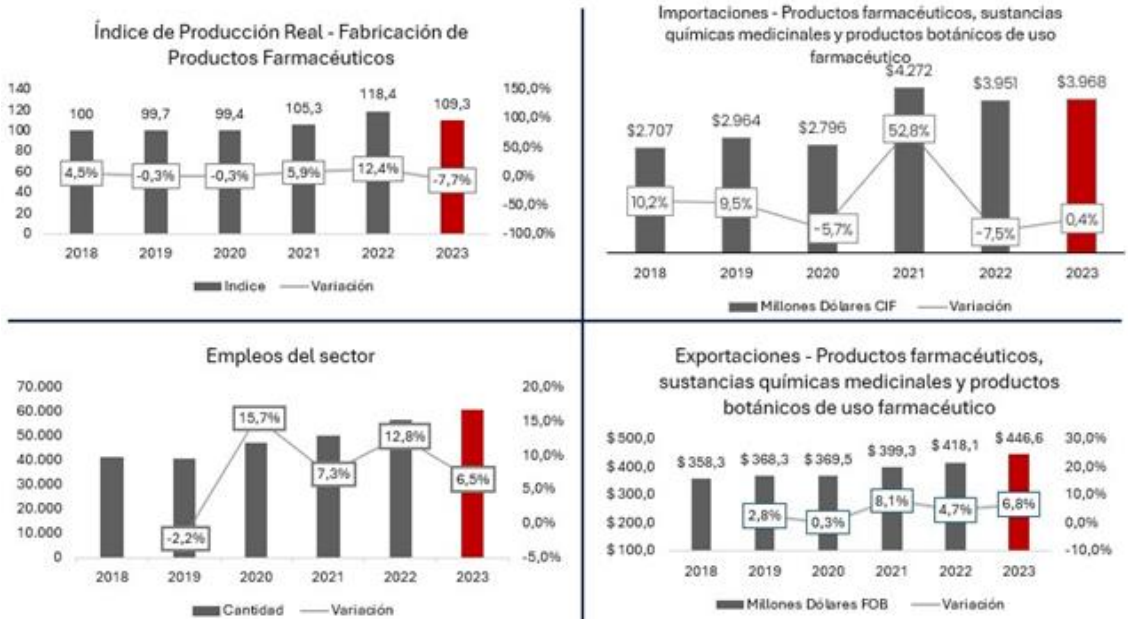

Figure 3. Colombian pharmaceutical sector

Fonte: Chamber of the Pharmaceutical Industry of the ANDI (2023)

However, drug distribution faces significant challenges, especially in terms of equitable access in different regions of the country. The concentration of production in certain geographic areas, as noted by Tailleman et al. (2016), can lead to disparities in the availability of medicines, mainly affecting rural and less developed areas.

Regulation and surveillance are fundamental pillars to guarantee the safety and efficacy of medicines. The National Institute for the Surveillance of Medicines and Food (INVIMA, 2019) plays a crucial role in the supervision and authorization of pharmaceutical products in Colombia. This strict regulation is consistent with the guidelines of the World Health Organization (WHO, 2018), which advocates for reforms in pharmaceutical systems to improve the accessibility and quality of medicines.

However, there are differences in the implementation and effectiveness of these regulations. While some companies comply with international standards, others face difficulties in adapting to regulations, which can delay the entry of new products to the market and limit innovation.

Colombia is a megadiverse country with enormous potential for research and development of medicines based on medicinal plants. The study by Rodríguez et al. (2016) highlights the richness of Colombian biodiversity and its pharmaceutical potential, underlining the importance of investing in research to develop new treatments and therapies.

However, the exploitation of this potential faces significant barriers, such as a lack of investment in research and development and the need for public policies that promote innovation. The Economic Commission for Latin America and the Caribbean (ARTECONA ET AL. (2020), 2017) emphasizes the need to strengthen public policies to encourage research and development in the pharmaceutical sector.

The geographical concentration of the pharmaceutical industry in certain regions of Colombia, such as Bogotá and Medellín, can influence collaboration and competition between companies, as well as

the availability of employment in the sector. Tailleman et al. (2016) identify a significant concentration of pharmaceutical companies in these areas, which can lead to greater specialization and efficiency, but also to regional disparities in terms of access to medicines and job opportunities.
The competitiveness of the Colombian pharmaceutical industry is essential for its growth and sustainability. According to the Ministry of Commerce, Industry and Tourism (2020), the industry has achieved greater participation in the international market thanks to improvements in production efficiency and product quality. The study by Charnes, Cooper and Rhodes (1978) on efficiency in decision-making suggests that there are still opportunities to optimize production processes and improve resource allocation.
The pharmaceutical industry has a significant impact on the Colombian economy, generating jobs, attracting investments and contributing to economic growth. The Bogotá Economic, Social and Environmental Development Plan (Mayor's Office of Bogotá, 2020) highlights the strengthening of the pharmaceutical industry as a strategic priority for the economic and social development of the region. In addition, the study by Haddad and Rios (2011) on the economic impact of pro-poor policies underlines the importance of evaluating the effects of public policies on accessibility to medicines and their impact on public health.
Government policies and regulation are crucial for the development of the Colombian pharmaceutical industry. ARTECONA ET AL. (2020) (2017) highlights the need to strengthen public policies in the pharmaceutical sector to promote innovation, improve accessibility to medicines and encourage research and development (Pérez, et al. 2018). In addition, the study by Dalai and Elquin (1992) on macroeconomic theory highlights the importance of considering economic and regulatory factors in the analysis of the pharmaceutical industry.
The detailed and expanded analysis of the Colombian pharmaceutical industry reveals a complex interaction of factors that influence its development and competitiveness. Productive efficiency, competitiveness, economic impact, regulation, innovation and biodiversity are key elements that must be addressed in a comprehensive manner to ensure access to quality medicines, promote innovation and contribute to the economic and social development of the country.

CONCLUSIONS

The Production Possibility Frontier (PPF) represents the maximum combination of goods and services that an economy can produce by efficiently using all its available resources. That is, the PPF defines the limits of what an economy can produce. In this case, it is indicated that the H, J, and I productions are "above" this production possibility frontier. This means that those production levels are unattainable or impossible to achieve with the available resources and productive capacity during that period (2021-2023). In other words, the H, J, and I productions exceeded the maximum production capacity that the country could efficiently achieve during that period, that is, they were produced above the country's real possibilities or productive limits at that time.
Considering the detailed analysis of the pharmaceutical industry in Colombia and the areas identified to improve its development and competitiveness, various lines of research can be proposed that could be explored in the future to strengthen the sector and promote innovation. Below are some possible areas of research to consider:
- Research in biodiversity and development of natural medicines given the richness of Colombian biodiversity, research could be carried out focused on the identification and characterization of bioactive compounds present in medicinal plants, with the aim of developing new natural medicines and alternative therapies.
- Optimization of production processes and efficiency: research that seeks to improve efficiency in drug production processes, through the implementation of innovative technologies, optimization of the supply chain and reduction of operating costs.
- Market and competitiveness studies: research that analyzes the competitiveness of the Colombian pharmaceutical industry in the global context, identifying market opportunities, emerging trends and strategies to strengthen the international presence of local companies.

- Regulation and public policies: research that evaluates the impact of government regulations and policies in the pharmaceutical sector, with the aim of identifying areas for improvement, promoting transparency and strengthening regulatory oversight to ensure the quality and safety of medicines.
- Technological innovation and product development: research that explores new technologies in the formulation and development of pharmaceutical products, such as nanotechnology, biotechnology and artificial intelligence, to create more effective, safe and personalized medicines.
- Sustainability and social responsibility: research that addresses environmental sustainability and social responsibility in the pharmaceutical industry, evaluating eco-friendly practices, corporate social responsibility programs, and strategies to reduce the environmental impact of drug production.
- Interdisciplinary collaboration and knowledge transfer: research that fosters interdisciplinary collaboration between academic institutions, pharmaceutical companies, and government agencies, with the aim of promoting knowledge transfer, open innovation, and the creation of research networks in the sector.

These lines of research could significantly contribute to the advancement and strengthening of the pharmaceutical industry in Colombia, promoting innovation, competitiveness, and sustainable development of the sector for the benefit of public health and the country's economy.

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