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The Impact of the Chemical Engineering Faculty's Research Activity at Universidad Pontificia Bolivariana: A Bibliometric Analysis

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Abstract: The Chemical Engineering Program at Universidad Pontificia Bolivariana (UPB) in Colombia will celebrate its 85th anniversary in 2023. This program is one of the oldest in the South American region. To commemorate the occasion, this work uses the bibliometric analysis and mapping tools to examine the evolution of the Faculty members' scientific output through time. 686 documents were analyzed in this work. Quantitative analysis enabled the identification of national and international cooperation, as well as preferred and most referenced journals. The evolution of trendy themes was determined by analyzing the authors ´keywords. The results reveal that Faculty teachers have been working on the most important subjects over time, cooperating with academics from 25 countries. The highest participation of female coauthors in at least 79% of the documents, as well as co-authorship with research from non-academic institutions that includes industry, are notable findings. This work contributes to recognizing the impact and relevance of the Chemical Engineering Program in Colombian society, as well as encouraging other writers around the world to assess the impact and contribution of their programs to societal development using tools such as bibliometric analysis.

Keywords: Bibliometrics; Chemical Engineering Education; Data Analysis; Educational Research; Faculty Development

1. Introduction

The Chemical Engineering education has traditionally been associated with the second industrial revolution, which took place between 1870 and 1914 (Mokyr, 1999), and some of the pioneers of teaching in these areas correspond to George E. Davis and the 12th lectures taught at the Manchester Technical School in England in 1888 (Aris, 1977). The Massachusetts Institute of Technology (IMT) effort, promoted by Dr. Lewis Mills Norton in 1888, represents one of the earliest strategies in the world connected to establishing a Chemical Education Program (Qian et al., 2023). Following the MIT strategy, American colleges such as the University of Pennsylvania in 1892, Tulane University in 1894, the University of Wisconsin in 1898, and the Armor Institute of Technology in 1900 offered Chemical Engineering courses (Van Antwerpe, 1980).

One of the earliest experiences in South America began in Colombia, especially in the Universidad Pontificia Bolivariana (UPB). When it was established in 1936, the UPB was one of the nation's

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first private, Catholic universities. Two years later, in 1938, the Chemical Engineering undergraduate program began operation, becoming the first in this country and one of the earliest in the South American region. This point is significant when compared to the situation of the University of Cambridge in the United Kingdom, which established its Department of Chemical Engineering in 1946 (Department of Chemical Engineering and Biotechnology, 2020).

One of the axes of the institution's existence as a catholic university has been research activities, especially curricular research. For example, in 1939, one year after the UPB was founded, the University's regulations mandated the establishment of research seminars to aid student training (Lotero Osorio, 2012).

Throughout the decades that followed, research efforts were focused on assisting and consolidating Colombia's newly formed chemical industry. However, considering the importance of providing integral solutions to the local society through a combination of social and technical approaches the Centro de Investigaciones para el Desarrollo Integral (CIDI) was founded on April 30, 1969 (Lotero Osorio, 2012). A few years later, it was evaluating the significance of establishing teams focused on particular fields. Environmental studies were established in 1975, followed by mechanical and testing (1979), energy studies (1979), chemical studies (1982), and leather studies (1983). The original purpose of these structures was to provide technical and laboratory help. These concerns have been combined with scientific studies over the course of decades. UPB today has about 80 research groups in various areas (Lotero Osorio, 2012).

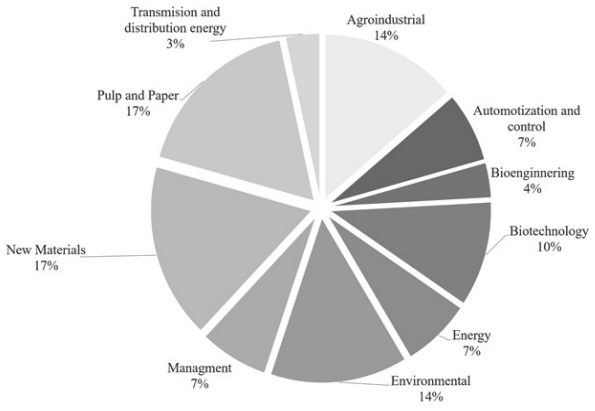


Fig. 1 : Distribution of Faculty Staff into Upb Research Group.

Staff from the chemical engineering faculty have been actively participating in research since the beginning of the CIDI's energy studies. Figure 1 depicts the current Faculty research participation. They are all members of a UPB research teams. These groups work on a wide range of topics, such as biotechnology, energy, environmental studies, materials, and automation and control research.

The Chemical Engineering Program will celebrate its 85th anniversary in 2023, and the purpose of this research is to answer the question, "How has the evolution of the research activities of the Chemical Engineering Faculty of UPB?" To develop this study, bibliometric analysis and mapping tools were chosen due to the benefits of analyzing the information that can be extracted from publications, such as affiliations, national and international collaborations, preferred and most cited journals, and topic trends based on the author's keywords. The use of mapping techniques in combination with bibliometric analysis is beneficial in illustrating patterns in data. (Cobo et al. 2011).

These methods have the advantage of offering a structural analysis to a large amount of data and inferring trends over time. Bibliometric analysis is being utilized more frequently in engineering study themes such as process safety and risk analysis (Tankin Amin et al., 2019) and carbon neutrality (Zhang et al., 2022). Also, in engineering education, subjects such as the case of engineering education considering aspects of sustainable development (Saraf & Pavan Kumar, 2023) are also covered. It has also been used to assess the influence of published papers in relevant journals such as Technological Forecasting and Social Change (Mas -Tur et al. 2021) or Journal of Business & Industrial Marketing (Valenzuela-Fernández et al., 2019). Despite this, as far as the authors know, this is the first study to apply bibliometric analysis to examine the influence of a Chemical Engineering Faculty's research efforts, particularly in the Latin-American context.

This study provides a comprehensive overview of the evolution of the Faculty's research publications from 1998 to 28 February 2023. Furthermore, given the scarcity of documentation on the impact of Chemical Engineering programs on society, this work aims to inspire other authors to evaluate the evolution and influence of their own programs in their communities.

2. Methodology

The Scopus and Scielo databases were used to collect the data for the analysis. Scopus is one of the most well-known abstract indexing databases in the world, whereas Scielo is one of the databases that accumulates information on Spanish and Iberoamerican production. Furthermore, both databases reveal pertinent Staff productions that have been certificated by the UPB Research Department.

To construct this study, the documents produced by staff members since 1998 were evaluated, which corresponds to the work of 39 teachers, 28 of whom are currently permanent members of the staff, and 53,6% of whom are women, demonstrating the significant relevance of the female participation in research activities.

The key stages of this project's implementation are depicted in Figure 2. The Faculty's initial publications are from 1975 and correspond to two works (Orr et al. 1975a, Orr et al. 1975b), both of which have 582 Scopus citations on February 28th, 2023. Despite this, the following Scopus document was issued in 1998 (Chejne et al. 1998). Faculty members have been publishing nonstop since this year. As a result, the analysis period, as shown in Figure 2 and described previously, covers from 1998 to 28 February 2023.

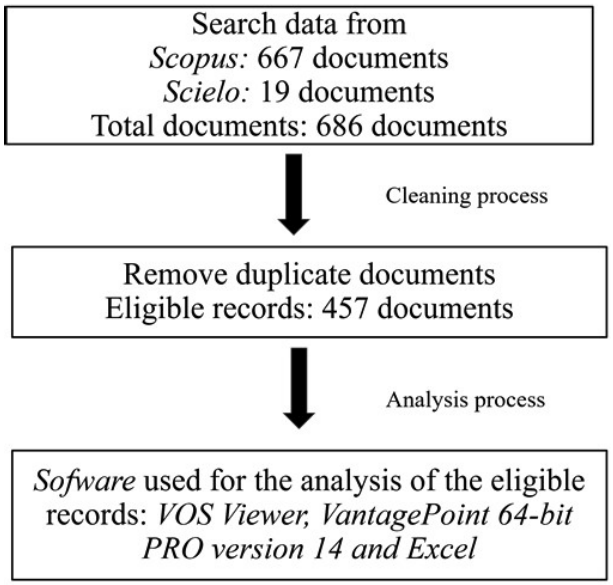


Fig. 2 : Key Stages For Conducting the Bibliometric Analysis.

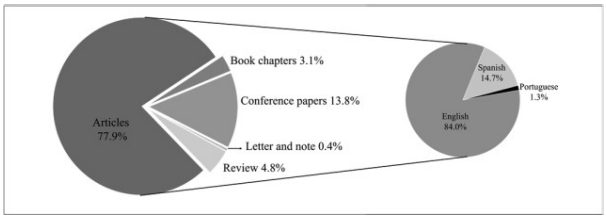
Because 68.5% of documents have at least two authors who are Chemical Engineering Faculty members, the reduction observed in Figure 2 between the initial founded records and the final analyzed corresponds to the elimination of duplicated documents.

The data from the selected documents was stored in comma-separated values (csv) files. These files were processed using VantagePoint 64-bit PRO version 14. Following these treatments, VOS Viewer, VantagePoint 64-bit PRO version 14, and Excel were used to examine the data, as shown in Figure 2.

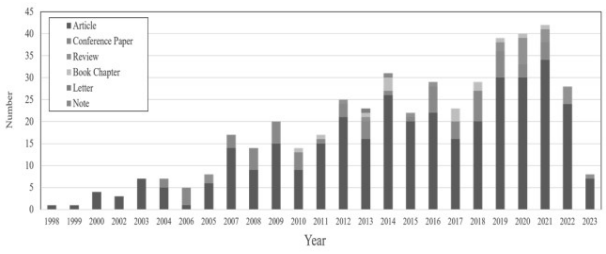
There was also a summary of the granted and pending patents. The UPB Research Area, which oversees the institution's patent process, provided and certified the data. The data was compiled on February 28, 2023.

3. Results

According to Figure 3a-b, the majority of Faculty staff production is in the form of articles, followed by conference papers. This publication tendency has remained over the time period under consideration (see Figure 3b). Furthermore, towards the end of February 2023, this output represented 10.7% of total UPB output reported in Scopus. This is important considering that the Chemical Engineering Faculty represents up 5% of the UPB staff members on the Medellin-Colombia campus.



a)



b)

Fig. 3 : Publication of the Faculty staff.
a) Type of the documents,
b) Evolution of the publications.

Figure 3a demonstrates that 84% of these documents are published in English, owing in part to the extensive worldwide collaboration. As illustrated in Figure 4, in addition to the intense collaboration with other Colombian authors, there are further collaborations with researchers from 25 countries, including the United States, Spain, Asian nations such as China and Turkey, and African countries such as Morocco and Nigeria. These collaborations involve writers from 97 different universities. In 93 documents, faculty members collaborated with 31 Colombian institutions. Ten of these institutions are non-universities, such as Andercol S.A and Compañía Nacional de Chocolates, as well as the Colombian government's Servicio Nacional de Aprendizaje and Area Metropolitana del Valle de Aburrá - Medellín. Higher collaboration occurs in 21 documents with Universidad Nacional of Colombia, 15 documents with Universidad de Antioquia, and 6 documents with Instituto. Tecnológico Metropolitano. These three universities are located in the Medellin - Area, where the majority of the Faculty members' activities take place. These intuitions are public universities, and the active publication demonstrates the good collaboration between private and public organizations, which is less common in the Latin American context, but it represents the UPB's well interaction with its academic environment.

Fig. 4 : National E International Collaboration.

To examine international cooperation in further depth, Figure 5 depicts the distribution of these collaborations in terms of the number of institutions involved by region and the percentage of papers where this collaboration occurs. Table 1 lists the top 15 international cooperation institutions. The presence of Spanish institutions is noteworthy. This result is related to shared cultural and linguistic traits as well as to the active international cooperation that the Spanish government actively promotes with Latin American states.

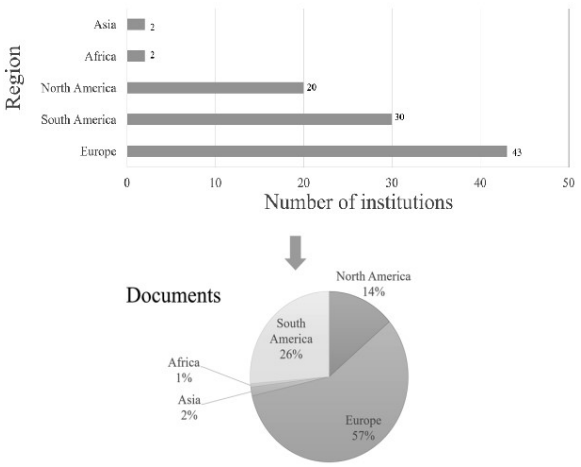


Fig. 5 : Distribution by Region And Percentage of the Documents Produced By International Cooperation.

Table 1 : Top 15 of Institutions With Higher Amount Of Collaboration

Institution	Number of documents	Country
1. Universidad País Vasco/Euskal Herriko Unibertsitatea	38	Spain
2. Instituto de Carboquímica	20	Spain
3. Universidad Tecnológica de Cartagena	17	Spain
4. Aalto Universtiy	11	Finland
5. Centre de Recherches sur les Macromolécules Végétales	10	France
6. Universidad de Granada	10	Spain
7. Auburn University	7	United States
8. North Carolina State University	7	United States
9. Universidad de Castilla La Mancha	5	Spain
10. University of Nottingham	5	United Kingdom
11. University of Amsterdam	5	Netherlands
12. University of Puerto Rico	5	Puerto Rico
13. Universidad de Girona	5	Spain
14. University of Rovira i Virgili	4	Spain
15. King Abdullah University of Science and Technology	4	Arabia Saudi

According to UNESCO, 33% of all researchers worldwide are women (Unesco). According to the results, at least one female author appears in 79% of the works studied and 76% of the articles. This pertinent information reinforces the Faculty's tradition of female involvement, which began with Rebeca Uribe Bone (1917-2017), the first female chemical engineer to receive a UPB degree and the first woman to graduate as an engineer (Osorio Cárdenas & Beltrán).

In this study, there were 218 journals found. Table 2 shows the top ten journals with the most articles, while Table 3 shows the journals with the most citations. The total number of citations supplied by Scopus is 10.193, which translates to a mean of 23.3 citations per document in this data source. It is

observed a variety of the subject areas that covers areas as materials sciences such as Cellulose, Bioresource, Carbohydrate Polymer, Molecules or Polymers; energy as the cases of Fuel or Renewable and Sustainable Energy Reviews; and general topics on engineering such as DYNA or Fluid Phase Equilibria. Despite that journal with higher amount of document corresponds to a DYNA, a Colombian scientific journal, it is remarkable the publication on journal higher ranked by the CiteScore 2021 such as Renewable and Sustainable Energy Reviews (28.5), Carbohydrate Polymers (16.0), Bioresource Technology (16.0) Fuel (11.2), or Industrial Crops (9.6).

Table 2 : Top 10 Of The Preferred Journals

Source title		Documents	CiteScore 2021	Scimago 2021
1.	DYNA - Colombia	13	1.2	Q4
2.	Cellulose	11	8.1	Q1
3.	Fluid Phase Equilibria	9	5.2	Q2
4.	BioResources	8	3.4	Q3
5.	Carbohydrate Polymers	8	16.0	Q1
6.	Fuel	7	11.2	Q1
7.	Industrial and Engineering Chemistry Research	7	6.6	Q3
8.	Industrial Crops and Products	7	9.6	Q1
9.	Molecules	7	5.9	Q1
10.	Polymers	7	5.7	Q1

Table 3 : Top 10 Of The Journals With Higher Citations

Source title		Citations	CiteScore 2021	Scimago 2021
1.	Carbohydrate Polymers	975	16.0	Q1
2.	Bioresource Technology	712	16.0	Q1
3.	Renewable and Sustainable Energy Reviews	554	28.5	Q1
4.	Cellulose	481	8.1	Q1
5.	Journal of Geochemical Exploration	338	7.5	Q2
6.	Polymer Composites	328	5.7	Q2
7.	Industrial Crops and Products	326	9.6	Q1
8.	Fuel Processing Technology	282	12.4	Q1
9.	Fuel	275	11.2	Q1
10.	Renewable Energy	251	13.6	Q1

Figure 6a-d depicts the evolution of the author's keywords from 1998 to 28 February 2023; these visualization graphics were developed with the VOS Viewer software. The occurrence of keywords in this study aids in analyzing a thorough knowledge of the research fields. The colors in these figures represent affinity clusters, while the text size denotes terms and their frequency of use.

This mapping analysis reveals that the themes are significantly heterogeneous. The colorful ellipses revealed certain affinities even if some topics have been separated and have no connecting lines. Red highlight ellipses accumulate the largest amount of words, while the other colors are associated with various categories, such as energy (green), biotechnology (orange), or common chemical subjects (black).

The density visualization of all keywords is shown in Figure 6a. The most promising themes, according to this study, include bacterial nanocellulose, natural fibers, biomass, gasification, and rice husk. However, as shown in Figures 6b-d, this tendency has changed over time.

As shown in Figure 6b, keywords from 1998 to 2008, the Faculty's first period of continuous publication, can be grouped into four clusters. First cluster refers to the development of novel materials based on the isolation of substances from agroindustrial and industrial wastes, such as banana fiber isolated from Musaceae waste plants or lignin obtained from paper industry waste. Physical and mechanical characterization are major aspects of these works, as evidenced by the keywords utilized in this cluster.

The second cluster covers research on different forms of energy including biodiesel and coal gasification. Controlling air pollution and physicochemical processes involving biomass are the topics of the third and fourth clusters, respectively.

According to Figure 6c, which covers the years 2009 to 2018, there have been increases in the number of clusters that represent the range of themes. However, two large clusters can be seen, one associated to the utilization of agroindustrial waste but with an increased amount of nanotechnology topics, and the other linked to the pollution of heavy metals.

Since this period, nanomaterials and pyrolysis have been consolidated as research topic. Faculty members have recently focused on potential themes such as circular economy, battery energy storage, agricultural biomass consumption, and bioprocessing (see Figure 6c-d). Moreover, since 2009, there has been a distinct combination of nanotechnology and biotechnology in research activities led by nanocellulose, particularly bacterial nanocellulose.

There are several parallels between the clusters in Figure 6d and the clusters seen in Figure 6c. Additionally, it can be observed that Figure 6d's

clusters 1, 2, and are marked in blue ellipses, are closely associated with the use of Colombian agroindustrial waste as raw materials for a variety of uses. Similar to Figure 6c, nanotechnology is a trendy topic at this time, especially in regard to nanocellulose. A noteworthy feature is the recently-consolidated emerging cluster 2, which is related to works involving silk fibroin.

Figure 6d makes it evident that scholars currently consider the importance of the circular economy, as demonstrated in the cluster 3.

As can be seen in Figures 6c–d, research into new energy sources and energy storage solutions is becoming increasingly important. Even during the most recent observation period, shown in Figure 6d, one of these distinctive options is the hydrogen subject.

Publications on the topic of biotechnology have begun appearing since 2009 (note the orange ellipses in Figure 6c–d), with an emphasis on biomedical and bioprocess studies.

The identified publications always include standard chemical engineering subjects such as process, modeling, control, and heat transfer (note the black ellipses in Figure 6a–d). However, these subjects don't seem to be related to the most popular topics (see red ellipses in Figure 6a-d). These findings suggest towards possibilities for future interconnected works.

These intensive research efforts over the last 25 years have contributed to the establishment of new undergraduate and graduate degrees at UPB. They are presented in Figure 7, and include the first undergraduate degree in Nanotechnology Engineering in South America. An engineering Ph.D. with primary topics in nanotechnology, biotechnology, and material sciences is one of the programs supported by this research experience. Other programs include a biotechnology major, master's degrees in biotechnology and engineering.

Figure 8a–c provides a summary of the granted and pending patent details. Staff members are the authors of 28.1 % of granted patents and 27.3 % of pending patents. Members of the Chemical Engineering Staff were part of the UPB team that received its first patent in 2008 (Universidad Pontificia Bolivariana, 2013). The granted and pending patents, as shown in Figures 8b–8c, focused on industrial processes, the utilization of waste as a raw material source, and Colombian agroindustrial fibers like fique.

4. Discussion

In order to commemorate the 85th anniversary of

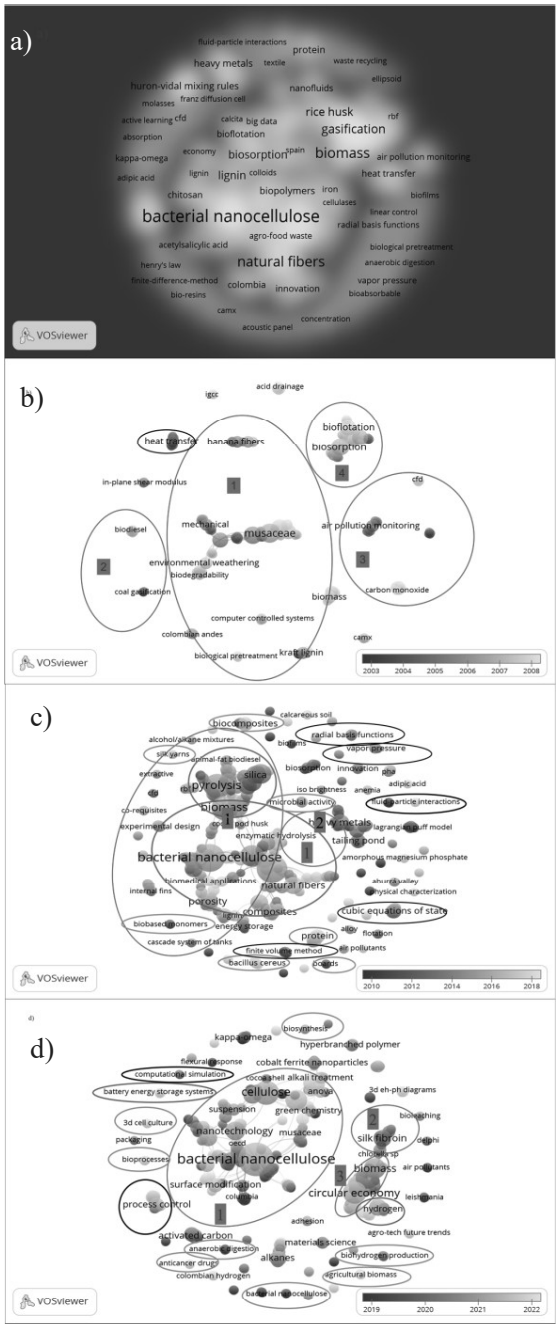


Fig. 6 : Keywords evolution.
a) Density visualization, b) 1998-2008, c) 2009-2018, and d) 2019- 28 February 2023.

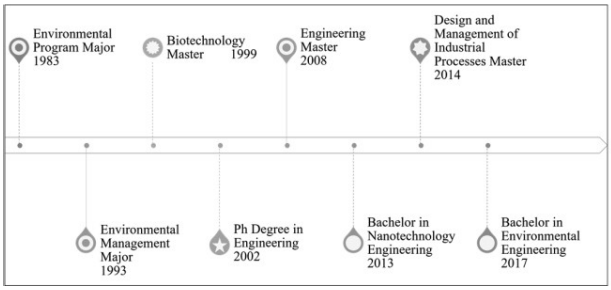


Fig. 7: Faculty-supported Graduate Program Timeline.

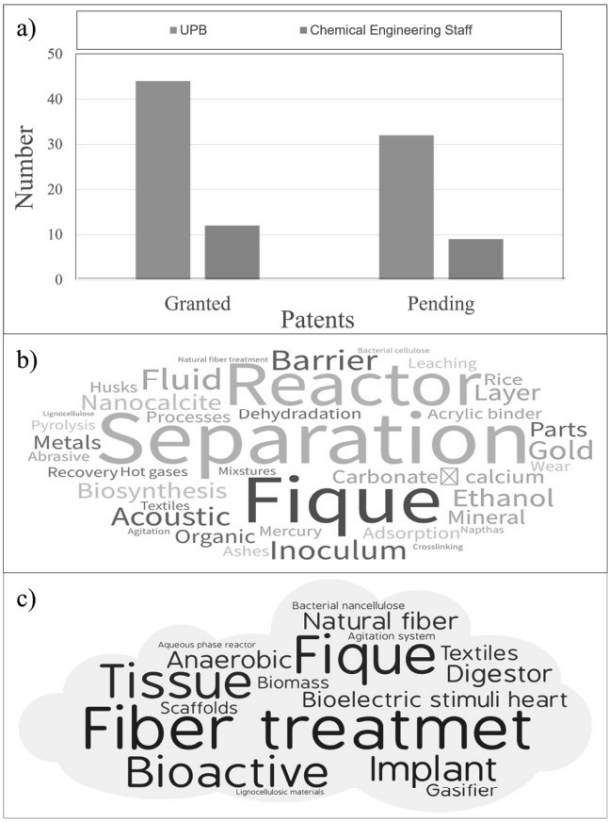


Fig. 8 : Patents – 28 February 2023.
a) Granted and pending patents,
b) Keywords of the granted patents, and
c) Keywords of the pending patents.

the UPB's Chemical Engineering Program in Medellin, Colombia, one of the oldest degrees in South America, this work summarizes the research tradition of the Faculty Members over the last 25 years, where research production has been generated continuously.

To learn more about this experience, the papers reported by Scopus and Scielo databases published by Faculty teachers were evaluated with the help of bibliometric analysis and mapping tools. As can be observed, production is gradually increasing, as evidenced by publications in high-ranking journals on specialized issues related to chemical engineering activities. It has been an extensive multinational collaboration involving research for 25 countries across six continents and publications in 218 journals.

The research topic has changed over the years, with continuing concerns about energy and the use of agricultural and industrial waste, as well as regular topics in chemical engineering and biotechnology. More recently, these subjects have also included hydrogen as an alternative energy source and nanomaterials developed from raw materials isolated from nature, like bacterial nanocellulose or nanocellulose. As previously pointed out, the poor connections between these many clusters provided the opportunity for future study, and this line, this new axis, which concentrates the extensive expertise and infrastructure can be related to biorefining.

The information regarding granted and pending patents shows that the subjects are quite comparable to those found in the analysis of the papers.

The implementation of biorefining based on Colombian industrial and agroindustrial waste is a tempting prospect because it allows for the inclusion of extensive pretreatment process knowledge, the creation of bioproducts from isolated substances, and the generation of bioenergy. The creation of this new research axis may serve as a catalyst for the creation of broad solutions driven by circular economy principles, and with the potential to have positive effects on society, the economy, and the environment.

This new research axis can be supported by the acknowledged expertise in the fields of nanotechnology, biotechnology, chemical engineering themes, and sustainability that has allowed the development of new academic programs.

On the other hand, concerns about process safety in the Chemical Engineering curriculum are becoming more and more important over the past three decades, especially in order to achieve a culture of high-safe processes with lower risk for the organization, environment, and communities (Thompson, et al., 2020; Ocampo-Lopez, et al., 2023). Despite the importance of the topic, only a small number of works—less than five—were found in these studies. As a result, future research should focus on how to integrate process safety into the curriculum and laboratory activities, especially in light of the

potential for new difficulties arising from the manipulation of nanomaterials (Bellagamba et al., 2023) and the unpredictable cyber-attack on chemical plants. Additionally, it is imperative to continue making improvements to the interaction between ethical considerations and process safety protocols

5. Conclusions

In this study, the influence of faculty members' research during the last 25 years was examined using bibliometric analysis and mapping methodologies. In addition, granted and pending patents were analyzed. The results demonstrate the program's applicability and effect through continuing investigation of the potential for using agricultural and industrial waste from Colombia as both raw materials and alternative energy sources. Other significant areas of research are the circular economy, nanotechnology, biotechnology, and new energy sources. These research experience supported the creation of innovative programs, including the Nanotechnology Engineering Program, one of the first in the South American area. Also, these results show the importance to focus the diverse research activity on an axis that conglomerates the experience. Biorefining is the axis that has been identified. But the further challenges associated with educating chemical engineering demanded additional study effort on ethics and safe processes. These new research directions must consider the ability to continuously transform in order to support social transformation.

This study serves as an example of how to assess program outcomes in order to motivate authors everywhere to look at faculty changes in order to assess the relevance of their research and identify developing trends that guided their research activities.

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