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Science in Mexico: a bibliometric analysis

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Abstract

We can find several studies analyzing the scientific production of Latin American countries, such as Argentina, Brazil, Colombia, Cuba, Guatemala, Peru, Venezuela etc throughout the scientific literature. There are many papers focusing on scientific disciplines, institutions and journals from these countries. However, to the best of our knowledge, we have not found any article that analyzes the scientific production of Mexico, global or recent and with Scopus as a specific database, nor the production in collaboration with its strategic countries in science and technology. For this reason, the present work intends to give Mexico the prominence it deserves by studying its productivity in research by using a bibliometric approach. To perform this study, the international bibliographic database Scopus was used within a ten year publication window from 2007 to 2016. With this sample, we analyzed the production in general, the scientific production in scientific disciplines, and production in collaboration with its strategic countries in science and technology, without forgetting the variables of the citations received from Scival as a parameter of impact on research. This study aims to serve as a precedent for later studies and contribute as a reference of Mexican production to the scientific community and as a tool to elaboration of national public policy in science and technology.

Keywords Scientific production · Scientific production by disciplines · Scientific collaboration · Strategic partners of Mexico · Citations received · Mexico

Introduction

Scientific production is considered as the materialization of the knowledge generated and the outcome of a process in which several agents intervene. The main ones are the public or private institutions that finance the research and, on the other hand, the scientists who are responsible of performing the research projects. This production is generally reflected in scientific publications. The researcher, research group, department, center, research

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organization or university disseminate their productivity to contribute to the growth and evolution of science. Price in 1963 recognized that science could be materialized in scientific publications and the scientist who collaborated in writing those publications (de solla Price 1963).

This production can be classified into different scientific areas, based on the indexing of the journals where the researchers publish. There are many classifications of disciplines, for example, undertaken by the OECD (Organization for Economic Co-operation and Development) or by databases such as WOS (Web of Science) or Scopus, nevertheless these classifications are very similar to each other. Scopus, the international and multidisciplinary bibliographic database, establishes the following 27 subject areas: Agricultural and Biological Sciences, Arts and Humanities, Biochemistry Genetics and Molecular Biology, Business Management and Accounting, Chemical Engineering, Chemistry, Computer Science, Decision Sciences, Dentistry, Earth and Planetary Sciences, Economics Econometrics and Finance, Energy, Engineering, Environmental Science, Health Professions, Immunology and Microbiology, Materials Science, Mathematics, Medicine, Multidisciplinary, Neuroscience, Nursing, Pharmacology Toxicology and Pharmaceutics, Physics and Astronomy, Psychology, Social Sciences and Veterinary. And there are specific subject categories where scientific journals are indexed within these disciplines (Scopus 2018; SJR 2018).

The terms bibliometrics and scientometrics have been presented almost concurrently by Pritchard and by Nalimov and Mulchenko in 1969. While Pritchard described the term bibliometrics as “the application of mathematical and statistical methods to books and other media of communication” (Pritchard 1969), Nalimov and Mulchenko defined scientometrics as “the application of those quantitative methods which are dealing with the analysis of science viewed as an information process” (Nalimov and Mulchenko 1969). According to these interpretations, scientometrics is restricted to the measurement of science communication, whereas bibliometrics is designed to deal with more general information processes. (Glänzel 2018). These metrics are often used to evaluate through its techniques and indicators the scientific production of countries, disciplines, journals, institutions, research groups, researchers, etc. There are numerous bibliometric studies which have analyzed the scientific production of Latin American countries (Sancho 1992; Spinak 1996; Shrum 1997) such as Argentina (National Scientific and Technical Research Council in Argentina—CONICET 2007), Brazil (Sidone et al. 2017; Da Luz et al. 2008), Colombia (Bucheli et al. 2012), Cuba (Arencibia-Jorge and Moya-Anegón 2010, Herrera-Vallejera et al. 2017), Guatemala (Monge-Nájera and Ho 2018), Peru (Vilchez-Roman 2014), Venezuela (Rojas-Sola and Jorda-Albinana 2010) etc.

A sample of bibliometrics studies was also obtained from Scopus focused on specific aspects of Mexico, such as the study of Arvantis et al. (1996) that analyzed the articles of Mexico in the database of the NCR (National Citation Report). Lima et al. 2005 published the results on the relationship between the number of links (number of links between the authors of an article) and a measure of group cohesion on a Likert scale in three research areas, Biotechnology, Mathematics and Physics at the UNAM (National Autonomous University of Mexico). Castillo-Pérez et al. (2015) analyzed the volume and impact of Mexican scientific production on influenza published in the SCI (Science Citation Index) between 2000 and 2012. Uddin et al. (2015) published a detailed scientific analysis of research in computer science in Mexico from 1989 to 2014 indexed in WOS. Franco-Paredes et al. (2016) described the scientific production of the Mexican Journal of Eating Disorders during the 2010–2014 period. Frixione et al. (2016) conducted a limited survey on the functioning and results of the SNI (National System of

Researchers) of more than 30 years, which is the main instrument of Mexico to stimulate competitive scientific and technological research. Hernandez-Garcia et al. (2016) studied steroid research between 1935 and 1965, indicating that the Syntex industrial laboratory in Mexico and the UNAM produced approximately 54% of the documents in the main journals in the area, which in turn generated more than 80% of the citations in this period. Villaseñor et al. (2017) analyzed the production profiles of the 50 most productive Mexican higher education institutions in Scopus, Elsevier's international bibliographic database. It is evident that many published works in Scopus have analyzed the scientific production of Mexico in a specific way.

There are 18 countries defined as Mexico's strategic partners by National Science and Technology Council (CONACYT), the decentralized public agency of the federal public administration responsible for the development of science and technology policies in Mexico. These countries are designated in terms of cooperation, alliances, common projects with Mexico (CONACYT 2016).

Searching on literature we noted the absence of papers which analyzes the entire scientific production of Mexico indexed in Scopus in a global and recent way, and neither the production in collaboration with its strategic countries in science and technology. Therefore we decided to analyze this sample for our study.

Consequently, we have studied a first pair (investment in research and researchers) as variables of a social and economic nature. The second pair (Scientific production of Mexico and citations received). And the third pair (Scientific production in collaboration with its strategic countries and thematic affinity with them). The vocation of a country is given by the areas that are considered of strategic priority. Accordingly, the vocation of the country has been analyzed through the disciplines in which Mexico mostly publishes and the repercussion on the discipline at a general level.

A series of research questions are formulated: Does investment in research and the number of researchers per million inhabitants evolve over time in Mexico? Does investment in research have a relationship with the number of researchers? Is scientific production progressing in Mexico? In what areas Mexico produces the most? What are the terms that Mexico uses more frequently in its scientific production? Which are the most productive authors and how are they related?

How is Mexico's collaboration with its strategic countries? Is the country which collaborates the most with Mexico is the one thematically closer?

The objective of this work is to analyze the scientific production of Mexico through the information downloaded from the Scopus database. The scientific literature has stated that there are not enough works that analyze this country in a general approach.

Methodology and data

The Scopus database has been used to extract the scientific production of Mexico because of its broad coverage. Scopus is the largest scientific database in the world and is the most complete, accurate and most widely used for bibliometric studies. This covers journals included in WOS (de Moya-Anegón et al. 2007), and its coverage is statistically balanced in terms of topics, countries, languages and publishers. In addition, Scival has also been used, which is based on Scopus data, to extract the total number of citations received. The data was downloaded in December 2017.

Mexican scientific production equals 177,574 documents. Mexico, as a Latin American country, also publishes in journals belonging to SciELO (Scientific electronic library online) database, therefore also the production has been extracted from this database.

The database of the UNESCO (United Nations Educational, Scientific, and Cultural Organization) Institute for Statistics has been chosen for the extraction of economic data for Mexico.

For the analysis of co-occurrence of terms and maps, the Vosviewer program of the University of Leiden has been used. This program is used for bibliometric analysis which represents maps of frequencies and co-occurrences with another appearance and more sophisticated visualizations, introduces a probability analysis with the mathematical Kernel algorithm.

We considered it interesting to add to the study an analysis of the scientific production in collaboration of Mexico and its countries considered by the CONACYT as strategic in Science and Technology. The countries are the following: Argentina, Brazil, Canada, Chile, China, Colombia, France, Germany, India, Israel, Japan, Russia, South Africa, South Korea, Spain, Turkey, United Kingdom and the United States (CONACYT 2016) .

The variables extracted from UNESCO were:

- Gross domestic expenditure on R&D (GERD) as a percentage of GDP (Gross Domestic Product) is the total intramural expenditure on R&D (Research and Development) performed in the national territory during a specific reference period expressed as a percentage of national GDP. R&D spending represents one of the main drivers for economic growth in a knowledge-based economy. As such, trends in the R&D expenditure indicator provide key indications regarding Mexico's competitiveness and future wealth.
- Researchers per million inhabitants: number of professionals dedicated to the conception or creation of new knowledge (who carry out research and improve or develop concepts, theories, models, instrumentation of techniques, software or operational methods) during a given year.

Variables extracted from Scopus, Scival and SciELO:

- *Scientific production* Total documents produced by Mexico during the study period from 2007 to 2016. All types of documents are considered (articles, conference proceedings, reviews, chapter of books, books, notes…). The scientific production of a country is the counting of documents with at least one author from that country (according to the affiliation that appears in the credits of authorship).
- *Scientific production of Mexico in the different thematic areas* Number of documents produced each year from the time window (from 2007 to 2016) in the 27 thematic areas of Scopus.
- *Citations* Number of citations received in the documents published in each year of the study. For example, citations received in 2007 from documents of 2008, 2009, 2010, etc.
- Scientific collaboration between Mexico and its strategic countries:

  1. On the one hand, documents in collaboration between Mexico and each strategic country. To give the same credit to each collaborating country, we have used the complete counting method instead of the fractional one: an article that represents

an international collaboration (with at least two different countries included in the authorship credits) is counted once for each country listed. Remembering that a publication is considered collaborative when there is more than one author in the field of authorship of Scopus. The scientific production of a country can be divided into: International collaboration, national collaboration, institutional collaboration and without collaboration.

2. On the other hand, in order to determine which partner is the most thematically analogous to Mexico we have studied the thematic affinity of Mexico with its strategic countries. For this, we calculated the percentage of relative collaboration determined by scientific disciplines between Mexico and its strategic countries.

Visualization with Vosviewer co-occurrence maps are commonly used to provide a graphic visualization of potential relationships between people, organizations, countries, concepts or other entities represented within scientific publications. The generation of these co-occurrence maps has become essential in text mining.

Co-occurrence is the interconnection of terms based on their matched presence in a designated unit of text. Networks link pairs of terms using a set of criteria that define co-occurrence. For example, it can be assumed that the terms A and B "co-occur" if both appear in the title of a particular article. The rules for delimiting the co-occurrence within a text corpus can be established according to the desired criteria.

Results and discussion

In this section the whole Mexican scientific production is analyzed throughout the years. A co-occurrence map is presented in order to discover which are the terms most repeated in the articles of Mexico. Likewise, the most productive authors of Mexico are represented. Finally, in the last part of this section we can observe the collaboration between Mexico and its strategic countries.

In the following table we can appreciate comparatively the Mexican scientific production in the different databases chosen for this study (Table 1).

In the last decade, Mexico's efforts have focused on achieving stronger scientific growth. However, these energies have not led it to achieve the productivity and growth necessary to reach other countries (OECD Science, Technology and Industry Scoreboard 017).

Mexico's R&D intensity is one of the lowest in the OECD area; gross domestic expenditure on R&D (GERD) is around 0.5% of GDP. Public institutions and universities continue to play an important role in R&D; the business sector finances 47% of R&D and performs just under 50%, below the OECD average. Structural changes are needed to position the country on a firm foundation to drive innovation, productivity and scientific growth (OECD 2018).

Some studies have manifested a stronger relationship between inputs (i.e., funding and human and economic investments in R&D) and outputs (i.e., generated results) (Moya-Anegon and Herrero Solana 1999; Rivera et al. 2009; Ebadi and Schiffauerova 2013; 2016; Aksnes et al. 2017). In order to check this with our data we have performed different Pearson correlations. For instance we found that the effect on research results of an increase in economic investment in science is manifested 3 years later, thus, it does not have an immediate influence. In this regard, expenditure on R&D is the variable with the highest predictive power for explaining a country's scientific output (Mueller 2016; Erfanian and

Table 1 Investment in research, researchers, scientific production and citations received in the years 2007–2016 (UNESCO, Scopus, Scival and SciELO)

Years	Total population (in thousands)	GERD as a percentage of GDP	Researchers per million inhabitants	Scientific production (Scopus)	Scientific production (SciELO)	Citations (Scival)	Citations (SciELO)	Annual production growth
2007	111,836	0.43	335.25	12,753	1787	203,084	2432	0
2008	113,662	0.474	327.37	14,162	2589	216,975	3484	1.90
2009	115,505	0.521	367.87	15,092	2768	206,924	3614	1.94
2010	117,319	0.537	324.55	16,006	3029	195,435	3454	1.94
2011	119,090	0.516	330.87	17,114	3486	188,589	3512	1.94
2012	120,828	0.494	238.34	18,374	3595	191,003	3121	1.93
2013	122,536	0.505	241.80	19,559	3778	150,510	2569	1.94
2014	124,222	0.538	240.07*	21,045	4083	122,888	1909	1.93
2015	125,891	0.534	240.94*	21,067	4666	87,238	1261	2.00
2016	127,540	0.502	240.51*	22,402	4280	48,751	541	1.94

*Missing data from UNESCO database

Neto 2017). Nevertheless Cole and Phelan (1999) have argued that wealth strongly, but not completely, influences the volume of research produced by countries.

The number of researchers in Mexico is quite small and even decreases over the years if we compare with the total population which is quite large and grows over the years. Mexico has few researchers despite having the National System of Researchers (SNI) which promotes both the quantity and quality of research in Mexico. As a result, the number of scientists who are members of the National System of Researchers is small (25, 072 in 2016).

There is a low and negative correlation between the investment in research and the number of researchers (r = −0.26). Therefore, the correlation between investment in research (2007–2013) and the scientific production (2010–2016) is r = 0.66. There is a positive relationship between the investment and the Scopus production in the country. With respect to the number of researchers (2007–2013) and production (2010–2016) the correlation is r = −0.68. While scientific production increases, the number of researchers decreases. With respect to SciELO production, the correlation with the investment is r = 0.52 and with the number of researchers is r = −0.77 similar to Scopus.

According to Power and Dusdal (2017a) which examined Germany, France and the United Kingdom, three leading countries in organizational development and scientific innovation. The differences in productivity in these three countries could not be completely explained by the differences in global investments or the number of researchers committed to science. If not, it is a matter of institutionalization and distribution of organizational forms in which researchers produce science. This remains crucial when analyzing factors more thoroughly with disciplinary emphasis. The key finding is that the institutionalization of the university research and the confidence in it seems to support high productivity. In fact Germany and France that have structured systems with a non-institutionalized university sector have less production than the United Kingdom, with a group of leading universities in the world that has attracted the best talent worldwide. Research universities are considered a fundamental principle in the connection between research and teaching, freedom to teach and to study, autonomy and commitment to science as well as the granting of doctoral degrees (Powell and Dusdal 2017b).

During the twentieth century, the United States quickly developed its capacity by fostering a broad base of research universities led by a small nucleus of highly productive "super research universities". This expansion was not the product of a centralized plan of science and higher education, but the increase of massive tertiary education in this nation (Fernandez and Baker 2017).

Regarding the tertiary education sector, there are 2.069 post-graduate programmes in Mexico. All in all 63.747 scholarships have been granted in 2016 (OIIP—Austrian Institute for International Affairs 2017). Taking as an example these great leading countries in science, for Mexico it would be interesting not only to increase the investment in research and the number of researchers but also the creation and development of the research universities.

The federal expenditure on science and technology in Mexico is distributed by the following administrative branches: CONACYT, Public Education, Energy, Agriculture, Health and Social Security, Economy, Environment and Natural Resources and Communications and Transport (CONACYT 2016).

In the following figure we appreciate the Mexican scientific production in the different scientific disciplines (Fig. 1).

The specialization profiles of Mexican scientific production are focused on Medicine, followed by Agriculture and Biological Sciences, Physics and Astronomy and

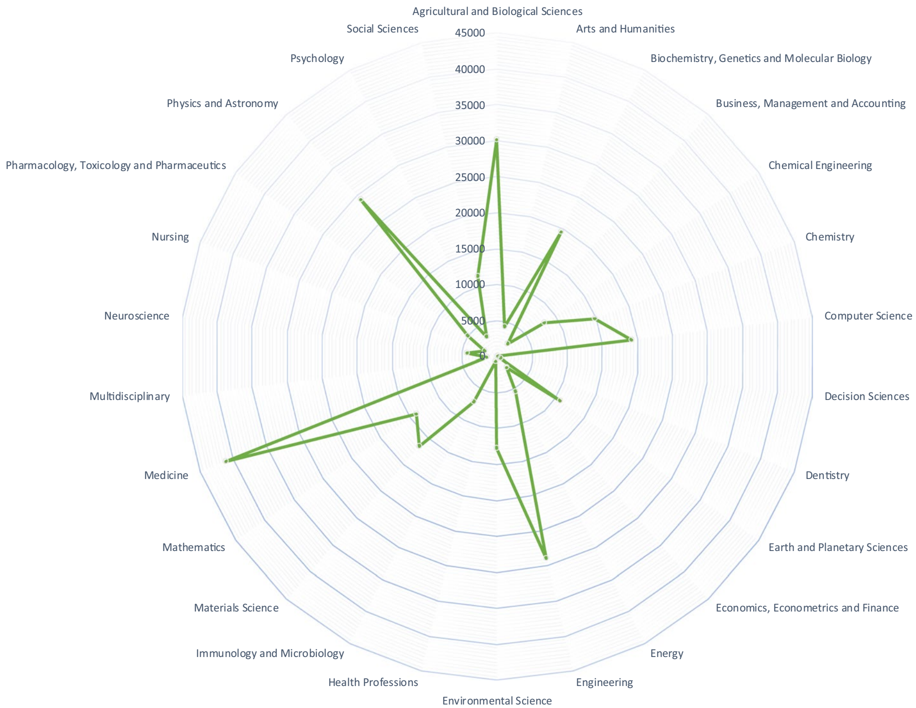

Fig. 1 Mexican scientific production sorted by scientific disciplines

Engineering. These four areas are quite separate from the others. The disciplines where there are lower levels of production are Decision Science, Dentistry and Health Professions.

The general pattern of scientific production by countries is extremely similar across most OECD countries when examining the fields with highest levels of scientific publication output. Medicine accounts for the largest number of publications in nearly all OECD countries, with exceptions found in China where Engineering was the dominant field, followed by Materials Science, Estonia (Agricultural and Biological Sciences), Indonesia (Agricultural and Biological Sciences), Korea (Engineering) and the Russian Federation (Physics and Astronomy, followed by Chemistry). The second largest most common field is Biochemistry, Genetics and Molecular Biology (16 countries) and Agricultural and Biological Sciences (10 countries) (OECD and SCImago Research Group (CSIC) 2016).

With respect to the total citations received, the area which receives the most total citations in Mexico is Medicine with a great difference from the others. Following this are three areas: Physics and Astronomy, Agriculture and Biological Sciences, and Biochemistry, Genetics and Molecular Biology. On the opposite side and with fewer citations are Health Professions, Dentistry and Economics.

Different fields in Mexico exhibit different citation patterns. Over the 2007–2016 period, documents published in Multidisciplinary journals attained the largest average number of citations per document (45.6 citations per document) within the Scopus database. This may be related to the prestige and attention that some of these journals attract, for example Nature or Science, and the possibility that scientists from different subject areas recognize relevant sources which they may not have otherwise known and cited (OECD and SCImago Research Group (CSIC) 2016).

Mexico excels in different fields, as implied by the number of citations received by their attributed documents. The disciplines that have the highest citations per document are Immunology and Microbiology with an average of 17.40 citations per document, Biochemistry, Genetics and Molecular Biology with 16.45 and Neurosciences 12.64. On the opposite side with the lowest data are Arts and Humanities with 4.38 and Social Sciences with 4.65 (Fig. 2).

In the following figure we have represented a term co-occurrence map based on text data from Mexican scientific production.

Full and binary counting are two ways of counting that can be used indistinctly according to the purpose of the study. Full counting means that all occurrences of a term in a document are counted. Binary counting means that only the presence or the absence of a term in a document matters and the number of occurrences of a term in a document is not taken into account. For this study we used the binary counting method instead of the full counting method.

We also have used total link strength attributes which indicate the number of links of an item with other items and the total strength of the links of an item with other items. For example, in the case of Co-occurrence links between terms, total link strength attribute indicates the total strength of the Co-occurrence links of a given term with other terms (VOSviewer Manual 2017).

Therefore, 100 is the minimum number of occurrences chosen of a term. Of the 247, 571 terms, 362 meet the threshold. For each of the 362 terms, a relevance score is calculated.

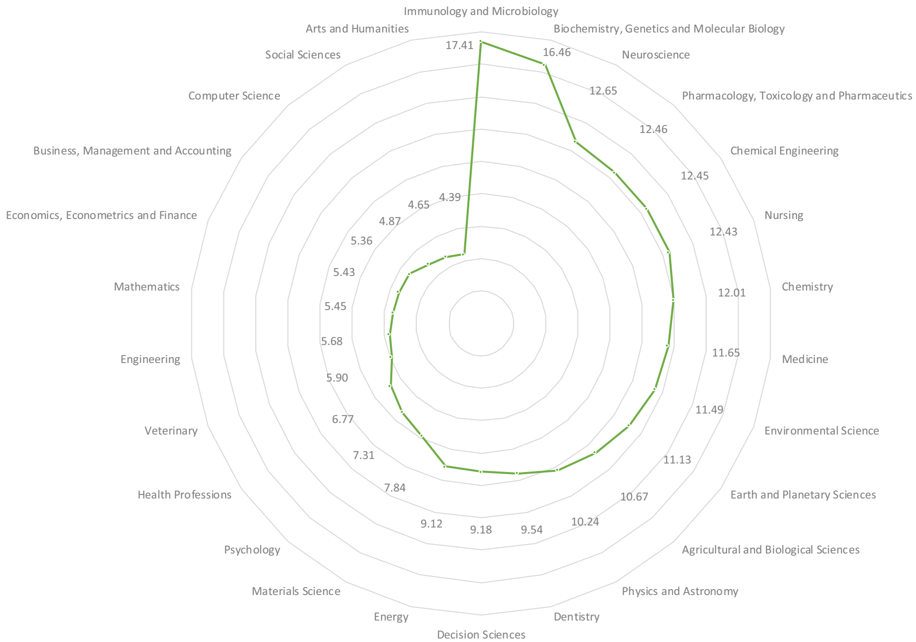

Fig. 2 Citations per document in the scientific disciplines. *We decided to remove Multidisciplinary from the figure for visualization reasons

Based on this score, the most relevant terms are selected. The default choice is to select the 60% most relevant terms. Finally 217 is the number of terms selected to visualize. We have used overlay visualization using the subtract mean as normalize scores. The association strength method has been applied. In order to expand the map the layout chosen is 3 attraction and 0 repulsion. And the weights are the occurrences (Fig. 3).

There are a total of 217 items, 7 clusters, 8511 links and 62,578 total links strength. The weight are the occurrences and the scores are the average of publications. The average publication year of the documents in which a keyword or a term occurs or the average publication year of the documents published by a source, an author, an organization, or a country.

The terms that have the highest number of occurrences are Mexico (cluster 3) (9489), Effect (cluster 1) (6254), Patient (cluster 2) (2881), Characterization (2506); Property (2080).

With respect to Relevance and Total link strength parameters the term Mexico has 0.51 and 9982 respectively; Effect 0.51 and 5844; Patient 0.70 and 3822; Characterization 0.70 and 2499; Property 0.70 and 1907.

The term Mexico is strongly associated (link strength) with Gulf (387), also with Effect (231), Characterization (156) and with Patient (125).

In the next figure we have created a co-authorship map based on Scopus bibliographic data. In a co-authorship analysis the relatedness of items is determined based on their number of co-authored documents.

The fractional counting method is chosen instead of full counting. Full counting means that each co-authorship has the same weight. Fractional counting means that the weight of a link is fractionalized. For instance, if an author collaborates with 10 others authors, each of the 10 co-authorship link has a weight of 1/10.

Of the 181,263 authors, 19,503 meet the thresholds. For each of the 19,503 authors, the total strength of the co-authorship links with other authors is calculated. The authors with the greatest total link strength are selected. A number of 500 authors are selected (Fig. 4).

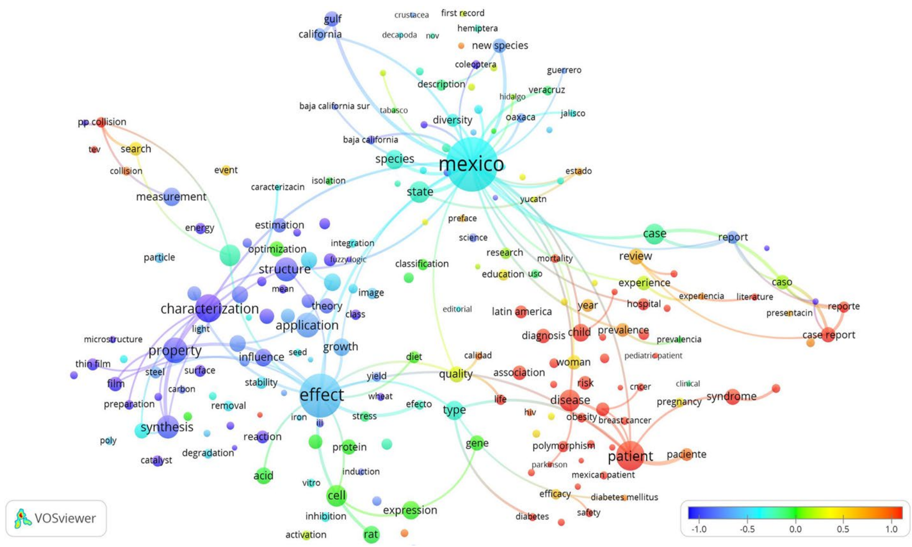

Fig. 3 Terms co-occurrence map based on text data from Mexican scientific production (2007–2016). An overlay visualization is performed

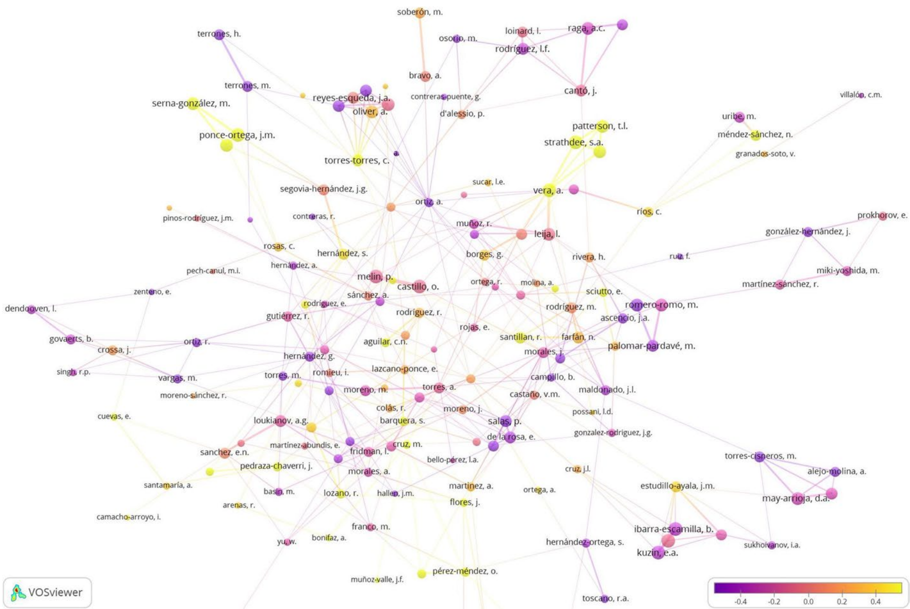

Fig. 4 Co-authorship map based on Mexican scientific production from 2007 to 2016. An overlay visualization is performed

Oscar Castillo from Tijuana Institute of Technology (Mexico)with a total of 302 documents is the author who appears most frequently, 5145 are the citations received and the total link strength is 229.0. Followed by this we find Patricia Melin from the same institution with 239 documents and a total of 4182 citations and total link strength of 190.00; Leonid Fridman of the National Autonomous University of Mexico with 188 documents and a total of 3264 citations and 92.00 total link strength.

The following is a density map where we have represented the relationship between authors, but this time the measure of visualization is the average of normalized citations.

Five is the minimum number of documents of an author, and 10 the minimum number of citations of an author. The number of citations of an author equals the total number of citations the documents of the author has received in Scopus. Fractionalization is the normalization method used for this analysis.

Of the 181,263 authors, 7576 meet the thresholds. For each of the 7576 authors, the total strength of the co-authorship links with other authors is calculated. The authors with the greatest total link strength are selected. A number of 500 authors are selected (Fig. 5).

Located In the central area of the map indicated by the color red are authors with significant centrality, co-occurrence and higher average of normalized citations. In the peripheral area with the color yellow are the authors with low average of normalized citations. Finally, the green color of the map is for those which get the least average of citations.

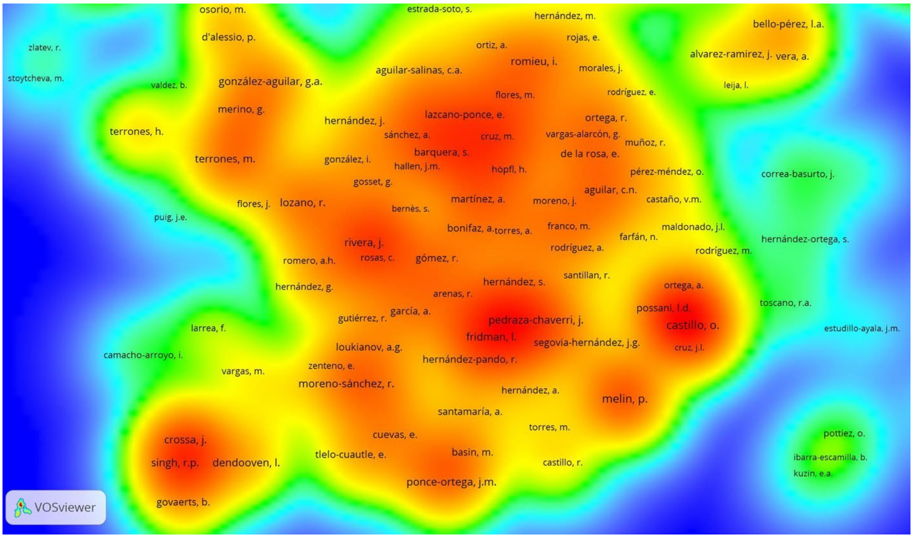

Fig. 5 Bibliometric map of co-authorship with normalized citations. A density visualization is performed

Mexico and its strategic countries

In this part of the paper we have analyzed the scientific production between Mexico and its strategic countries in science and technology in order to notice how these alliances are being performed.

The actions of Mexico in international cooperation are focused on the conformation and implementation of specific work agendas with the countries and regions defined as strategic and priorities in the Special Program of Science, Technology and Innovation (PECiTI) and the Program Institutional of CONACYT, with the purpose of continuing to strengthen the Internationalization of activities and public policies in science and technology: (1) Develop and consolidate international cooperation agendas with strategic countries contributing to the scientific and technological development of Mexico; (2) Negotiate and implement joint mechanisms in support of scientific research and technological development, through schemes and modalities of collaboration with international actors; (3) Manage the International Cooperation Fund in Science and Technology (FONCICYT) as a financing and coordination tool; (4) Support the negotiation of agreements and instruments to promote cooperation at an international level, such as the training of high-quality human resources, scientific development, technological innovation, among others (CONACYT 2018).

The collaborative scientific production between Mexico and its strategic countries is 61,594 documents in the years 2007–2016. We can observe its evolution over the years in the following figure (Fig. 6).

We can observe that production in collaboration has increased over the years due to the contracts, scientific plans, collaboration agreements that have been engaged with partners. In fact the scientific production in common in 2007 was 4510 while in 2016 was 8083.

In Fig. 7 We can observe on the primary axis the scientific collaboration between Mexico and each of its strategic countries and; on the secondary axis we can detect the degree of thematic affinity with its partners.

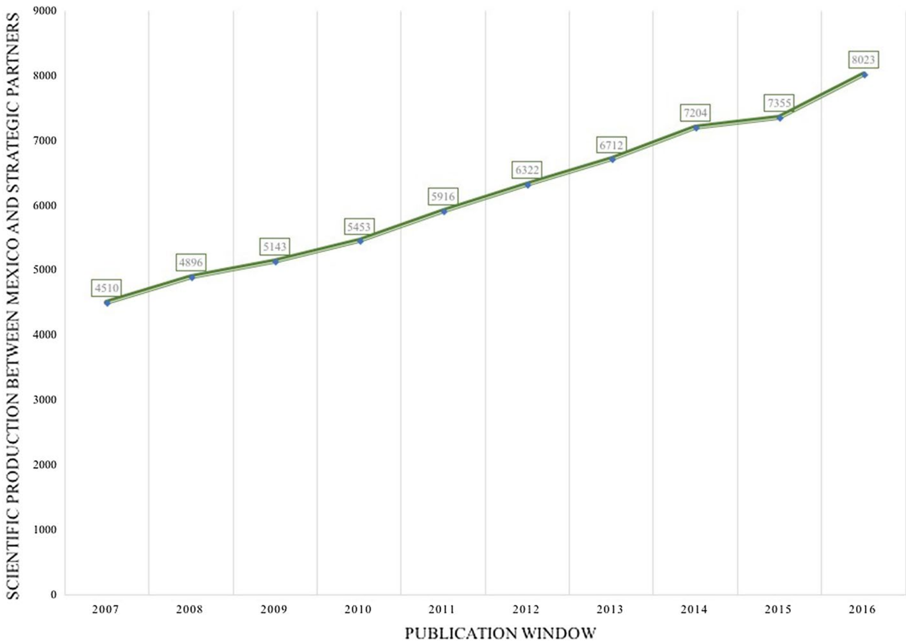

Fig. 6 Evolution of the collaborative documents between Mexico and its strategic countries in Science and Technology

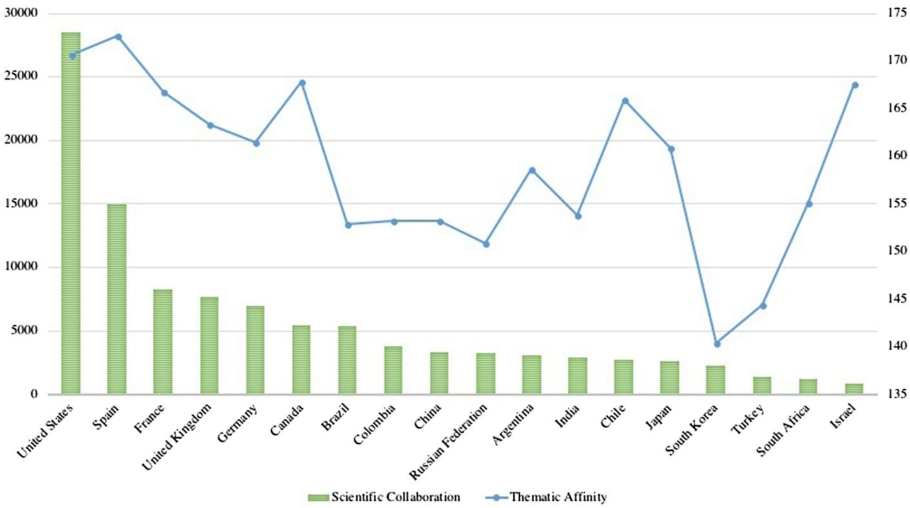

Fig. 7 Scientific collaboration and thematic affinity between Mexico and its strategic countries

The countries which collaborate the most with Mexico are the United States (28,535), Spain (15,003) and France (8249). On the opposite side are Israel (881), South Africa (1220) and Turkey (1405).

In order to calculate the thematic affinity of the percentages of scientific collaboration between Mexico and its strategic countries in each of the 27 thematic areas relative to the total production are calculated.

Spain is the country thematically closest to Mexico according to its relative percentages by areas. Followed by the United States, Canada and Israel. The evidence that Mexico is closest to Spain is not surprising since both countries have a historical union and great similarities as a country. This opens the possibility of a new study in which the scientific collaboration between Mexico and Spain is analyzed in depth.

Regarding Mexican–European cooperation, Mexico identifies the fields of health, energy, society, environment, sustainable development and technological development as priority areas (OIIP—Austrian Institute for International Affairs 2017).

Physics and Astronomy (29,779) is where Mexico publishes more documents in collaboration with its strategic countries. Followed by Medicine (20,924), Agricultural and Biological Sciences (15,411), Engineering (12,040) and Biochemistry, Genetics and Molecular Biology (11,808). The areas where Mexico has lower documents in collaboration are Dentistry (359), Health Professions (644), Decision Making Sciences (689), Veterinary (940) and Economics, Econometrics and Finance (981) (Fig. 8).

We detect that Italy is a country that collaborates considerably with Mexico, even more than other countries that are considered strategic partners, however, CONACYT does not currently regards it as strategic.

In the following figure we represent a term co-occurrences map from the scientific production of Mexico and its strategic countries.

Of the 40,027 terms, 528 meet the threshold. For each of the 528 terms, a relevance score is calculated. Based on this score, the most relevant terms are selected. The default choice is to select the 60% most relevant terms. Finally, 200 is the number of terms selected to visualize (Fig. 9).

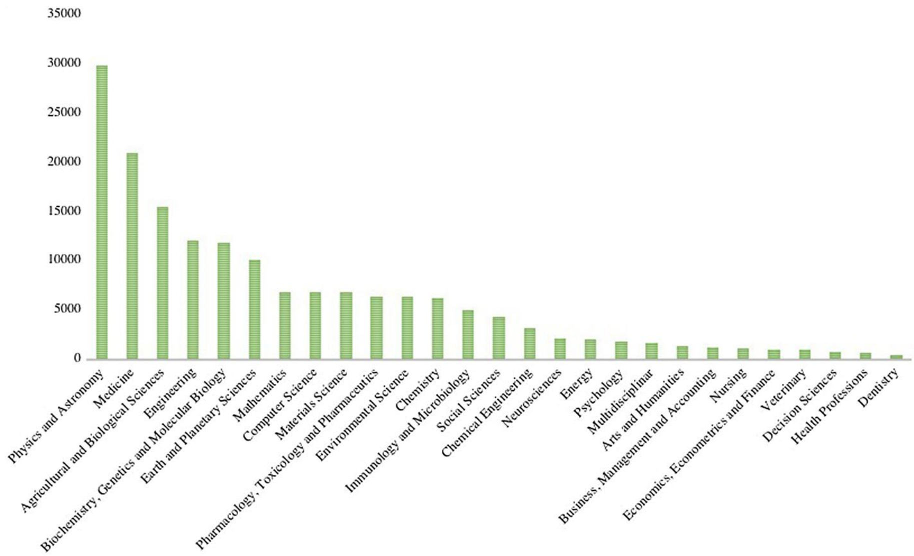

Fig. 8 Production in collaboration between Mexico and its 18 strategic countries in the different subject areas

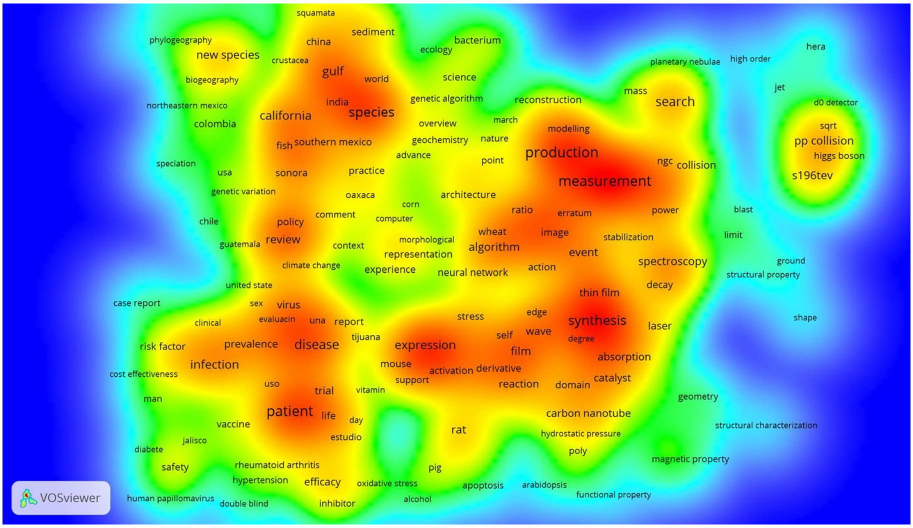

Fig. 9 Terms co-occurrence map based on text data from scientific production between Mexico and its strategic partners (2007–2016). A Density visualization is performed

There are 7 clusters, 200 items, 2345 links, 4528 total link strength. The terms that have the highest number of occurrences in the documents between Mexico and their strategic countries are Measurement (229); Patient (208); Production (198); Synthesis (198); Species (184).

With respect to Relevance and Total link strength parameters the term Measurement 0.51 and 252 respectively; Patient 0.68 and 205; Production 0.39 and 213; Synthesis 0.71 and 99; Species 0.56 and 143.

There is a similarity between the terms that appear most in the total production of Mexico and with terms in the collaborative documents. This could be due to the fact that the collaborative production of Mexico with its strategic partners represents 34% of the total of the general scientific production of Mexico in these years. The scientific production of Mexico has benefited by these types of collaborations.

Conclusions

In view of the data extracted from the sources and the results of this study, investment in research in Mexico has not evolve over time, if it does not remain stagnant in fact GERD as a percentage of GDP is around 0.50 on average. With regard to researchers per million inhabitants, it should be noted that they tend to decrease over time.

There is a low and negative correlation between investment and the number of researchers. The number of researchers is decreasing over the years.

Scientific production has increased over the years in Mexico despite its low investment and the small number of researchers per million inhabitants. There is a positive and medium high correlation between scientific production and investment in research.

By identifying what makes countries successful in science, long-term development and the development of research universities are identified. Not only has the size of the country, nor the level of investment in science and technology, nor the number of researchers fully explained the growth of scientific productivity. In the case of Mexico, apart from increasing the investment, it should invest more in the creation of a scientific culture and the development of research universities, recruiting talent from all over the world, since it has been shown in countless studies that the universities that have promoted the research university have had a considerable increase in scientific production in the last decades.

Medicine is the area with the highest production in Mexico, in fact it has a great difference from the others. Agricultural and biological sciences, physics and astronomy and engineering are the following areas in production after Medicine. All three have a similar production. Decision Sciences, Dentistry and Health Professions are the areas with the least production.

However, the areas with the highest number of citations per document are Immunology and microbiology, Biochemistry, genetics and molecular biology and neuroscience. The lowest number of citations per document are the areas of Arts and Humanities and Social Sciences.

The most repeated terms in the Mexican documents are the words: Mexico, effects and patient these three words are very much related to each other. When finding the word Mexico as the most repeated in the documents it is understood that researchers are very focused on studying what is related to their own country. The word Effects as the second most used term and the third related to Medicine is the term Patient.

Oscar Castillo of the Tijuana Institute of Technology is the author who produces the largest number of documents, the one who gets more citations and the one who is most related to other authors, since he has a total link strength of 233. The following is Patricia Melin close collaborator of Oscar Castillo, With 239 documents, a total of 4182 citations and a total link strength of 198.

Leonid Fridman is next with the highest production, however Mauricio Terrones obtains more citations with fewer documents. Regulo Lopez-Callejas and Antonio Mercado-Cabrera both from the National Nuclear Research Institute are the next to have a greater total link strength (191 and 190 respectively)

There are 18 countries declared strategic for Mexico by CONACYT. Over the years you can see an evolution in the number of collaborative documents between Mexico and its strategic countries in science and technology. In 2007 the total number of collaboration was 4510 and in 2016 a total of 8023. The strategic country that collaborates the most with Mexico is the United States, followed by Spain. On the contrary Israel and South Africa are the countries that collaborate the least.

With the indicator to measure the thematic affinity we can say that the country most thematically related to Mexico is Spain. This is not surprising since both countries have a close historical relationship.

Physics and Astronomy is the area where Mexico collaborates the most with its strategic countries, followed by Medicine and Agriculture. Italy is a country which a large number of documents in collaboration with Mexico, despite not being considered a strategic country.

After applying this approach to Mexican scientific production, the idea has emerged to deepen the citation flows in Mexico, analyzing in detail its citation and references habits, and if there is some kind of pattern defined in the production from different scientific disciplines.

The 34% of Mexico's production is due to the collaboration with strategic countries, therefore, they should create more scientific alliances, getting involved, committing their effort and experience in order to achieve a common purpose in which all of them could benefit. These collaborative projects of Mexico and its strategic countries could generate evolutionary spaces where great diversity, social skills, national values and cultural patterns would converge together. This study opens a window to cooperation, so that more collaborations could be done among all strategic countries and thus could be enriched from the scientific point of view. Mexico is eager to keep working in its current cooperation agreements and to increase cooperation with other partners.

Finally, we believe this study is also relevant for CONACYT because it provides a state of the art study of Mexico and strategic countries in science and technology with data from the Scopus database. The study can make CONACYT consider its strategic countries and open new initiatives for scientific collaboration. This could help realize how these strategies are being carried out, rethink, modify the list of partners or add new ones. It is a general radiography of the state of Mexico and its strategic partners that could greatly benefit the country and CONACYT for decision making.

Final considerations

The findings have shown that Mexico produces novel science, despite the few economic resources allocated for science that come from government and private company funding. In Mexico, most of the investment in research emanates from government sources. It would be necessary to encourage and incentivize the private sector to invest more in science as it occurs in other countries where the greatest weight of investment comes from the private companies, since this fact has a positive impact on research results.

Consequently, that governments and private sectors become aware of the imperative necessity to increase investment in R&D in Mexico will make the country's scientific production increase in quantity.

With regard to the strategic countries for Mexico, production should be stimulated in collaboration among all creating a spectrum of diversity and cultural richness in the works.

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Compliance with ethical standards

Conflict of interest All authors declare that there is no conflict of interest.

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