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Article

Scientific Production on Technological Cooperation Networks in Biotechnology sector

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Abstract: The present study aims to analyze scientific production about technological cooperation networks in biotechnology sector, based on bibliometrics network analysis. We used the Gephi software to identify groups of partnerships, proving that the cooperation relationship is a practice used, resulting technological development. Findings identify that in the path for new resources that complement skills and competences universities are an important player in this cooperative ecosystem, and The United States is a large hub, with an extensive network of global cooperation. A strong role of its researchers in the publication of scientific articles in cooperation is highlighted. This study contributes to the advancement of the discussion about cooperative networks, as well as to the development of policies aimed at the biotechnology sector advancements.

Keywords: Technological Cooperation Networks; Biotechnology sector; Bibliometrics; Social Network Analysis.

1. Introduction

Companies are increasingly challenged to remain competitive and innovative in their markets. The complexity of the organizational context and the dynamics of the markets have encouraged companies to seek new organizational arrangements for their business models.

The biotechnology sector [1] relates to open innovation because it uses external sources of knowledge to improve its capacity to innovate through collaborative efforts. These efforts are key factors for biotechnology industry development and its business management innovative capacity and are intensified through mutual trust [2].

Biotechnology companies develop themselves in a complex and dynamic system of cooperation networks, formed by many actors such as, universities, research institutes, investment funds, government agencies, pharmaceutical laboratories, and other partnerships [3]. These actors use a variety of arrangements to achieve a dynamic knowledge flow through an intensive of professionals' relationships into different directions.

The impact of cooperation for innovation is not only mediated by the proximity of these actors, but also by their level of networks intensity from the cooperation [4]. Therefore, we pursue to identify in this bibliometric study which level of cooperation exist in the literature and the relevance of technological cooperation networks for the biotechnology sector because there is no convergence regarding the systematization of scientific production and the configuration of research cooperation networks for technological development.

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Research on the association between networks of technological cooperation and patents in biotechnology is nominal [4,5], and few studies consider the intensity and the relationship of such networks based on bibliometric data [6,7,8]. We intend to contribute to the advancement of scientific knowledge from the mapping of the theoretical-conceptual framework, as well as to the development of policies aimed at the biotechnology sector advancements.

2. Theorical background

Biotechnology sector has in its essence a tremendous potential to innovate, and operates in several sectors, such as health, agriculture, environment, and others. Its importance to develop regions and countries, in general, can be illustrated by the capacity of promoting national development generating jobs and supporting the economies. Modern biotechnology is characterized by the complexity and multidisciplinary of the knowledge and the high dependence on research, and high risks involved in the development of a new discovery [1]. For organizations that using biotechnology the relationship between knowledge management and business performance is distinctive [9].

The development of biotechnology sector is causally related to the establishment of inter-organizational partnerships and consequently, the intensification of cooperation networks which allow companies and / or institutions to have access to specific knowledge sources [10]. Thus, interorganizational cooperation along the value chain is essential for cocreation and innovation [11], as well as for knowledge transferring [12].

Cooperation networks emerged in organizational field to group attributes that allow companies to adapt to competitive and dynamic environment [13]. Thus, networks contribute to aggregate complementary knowledge and skills [14] and gain competitive advantage [15].

Cooperation also appears as the alternative for companies to acquire new resources and knowledge in the search for innovation. Chesbrough [16] conceptualizes this model as "open innovation". In the current paradigm of open innovation (OI), research on collaborations between actors are considered especially important for the development of science and technology [17,18,19].

The term "open innovation" was created with the purpose of defining the network nature of innovation mechanisms. Open innovation in this study is considered as a paradigm that assumes that companies can and should use external ideas, as well as internal ideas to seek and make advancements in technology [17]. The theory of open innovation provides important insights into intensified role of accessing knowledge and networks to facilitate innovation through innovative processes [16,17,20,21]. Chesbrough and Bogers [22] in more recent definitions, emphasize that the main feature of innovation is the organization's ability to manage these knowledge flows.

Companies participating in multiple cooperation networks can represent a complementarity in various projects in which they are involved, benefiting strategic choices for innovation [23]. Bengtsson and Sölvell [24] demonstrate that the intensity of interaction in networks is positively correlated to the generation of innovations. Conversely, companies that are not engaged in cooperation and knowledge exchange limit their knowledge base [25]. Recent literature also highlights biotechnology companies operating naturally in collaborative networks maintaining partnerships with universities to increase their innovation capacities [26].

Torres-Freire et al. [27] observed that the economic activity involving biotechnology has high technological intensity and does not develop without communication between private (companies), public (governments/agents), and academic (institutions / universities) sectors. This integration refers to "Triple Helix" concept, which proposes a dynamic relationship between state and science conducted in universities and materialized by technology developed in companies [28] (p. 112). A technological cooperation network is essential for companies in the biotechnology sector, given the competitive and intensive nature of knowledge, making these networks the main sources of innovation [1].

Many countries have introduced a series of measures to strengthen links between industries, universities, and public research institutes focusing on achieving innovation, technological development, and improving national economic performance [29].

3. Methods

Bibliometric studies emerged as an accurate method to assess the contribution of an article to the advancement of knowledge. According to Narin et al. [30], the basic principle of bibliometric analysis is the quantification of scientific publications by means of technical performance parameters for determining productivity. Hence, this research was completed on the Web of Science portal, in the period of June and July 2019, using keywords and terms involving "networks of technological cooperation and patents in biotechnology". The research was conducted by the Web of Science Core Collection, allowing research coverage in the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (AHCI), published from 1988 until 2019.

The Linguee dictionary, developed by Gereon Frahling, was used as a tool to support the choice of words, terms, and expressions. This tool presents characteristics that distinguish it from a traditional dictionary, as it not only shows the entries and their respective translations, but also generates a Parallel Corpus, containing the searched word or phrase. The phrases that comprise the corpus are found by programs called network crawlers (web crawlers). The trackers are updated as they allow the dictionary to constantly have new data [31].

The construction of the search expression of this research was formed by associating the words "cooperation" and "collaboration", using the boolean "OR" between them, since both words are commonly used in articles that refer to cooperation. The words "network" and "technological" were added to the search expression and the word "patent", with the special character (*) added to expand the search and identify possible variations aiming to highlight the cooperation between the actors in this research field. As final objective, we added "technological cooperation networks" to the biotechnology segment, using the boolean "AND" so that it could verify the simultaneous occurrence of the other terms in relation to the biotechnology segment. To summarize, the search term used was: ("cooperat * or collabor * or network * or technol *") or patent *) and biotec *.

Gephi software, version 0.9.2, analyzed social networks and was created focusing on the construction, visualization, and analysis of technological cooperation and patents in biotechnology, considering the bibliometric data obtained [32]. Social Network Analysis (SNA) is a powerful approach tool to get answers about behavior between individuals or organizations, as well as to understand patterns and main influencing agents within a theme [33]. It explores the relationship ("loops", "arcs", or "edges") between the actors (known as "we" or ''vertices").

Initially, a bipartite network was built, in which the nodes are the organizations that are connected through other nodes that represent the titles of the works. In a second step, the nodes with the names of the articles were transformed into edges that connected the organizations, forming the final network. Modularity, grade, weighted average grade, and PageRank [34] were the statistics adopted for the necessary analyses and conclusions [35]. And finally, for the construction of networks, data such as title, authors, and address (institution and country) of the authors were exported and treated with Microsoft Excel resources, for authorship data could be obtained.

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At this stage of the research, it was possible to identify, from the analysis of social networks, the relationship between organizations (universities, research centers, or companies) in which the research was developed. This means that the actors were recognized as hubs in the systematized cooperation networks or as bridges between the different subnets [36].

4. Results

After carried out a detailed analysis of the main publications on the theme, the networks were built so that the work of the main researchers about "networks of technological cooperation and patents in biotechnology" could be evidenced.

4.1. Publications and citations

The search criteria used in this study yielded a total of 666 articles. The articles have a total of 10,085 citations distributed over the period of the study and an average of 22.2 publications and 336,17 citations per year (Figure 1). We observed the majority of publications among 2011 until 2014. After 2000, publications were practically over 20 editions per year showing a steadiness.

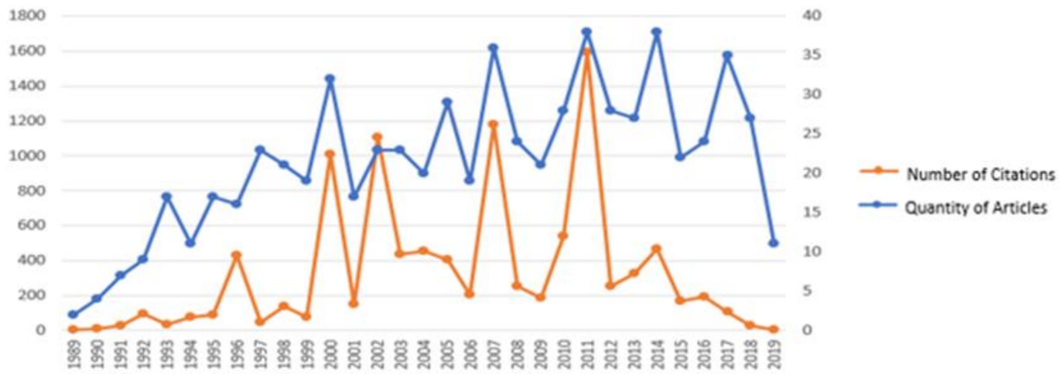

Figure 1. *Evolution of articles and citations. Source: Based on processed data by the authors*

4.2. Countries and publications

The United States leads the ranking with 205 publications, followed by England (60 publications), Germany (49 publications), and Italy (31 publications), make up a representative block in scientific production in technological cooperation networks and patents in biotechnology.

We identified, the strength of cooperation assessed by the number of cooperative works, that is, in co-authorship, each country has. This indicated the connection and interaction that a country has with other countries in collaborative scientific research. The sharing of information, the union of competences, and the efforts of researchers in the search for common goals boost the production of knowledge [37] and it is possible to claim that co-authorship in scientific publications is an indicator of collaboration [38].

According to Capaldo [39], the strength of the relationship can be expressed in terms of the total duration of the relationship, frequency, or intensity of the collaboration. It is assumed that the more lasting, frequent, or intense the collaboration, the greater the strength of the relationship. According to the Organization for Economic Co-operation and Development – OECD [40], the strength of the relationship is considered an important variable, since it positively affects trust between partners and the transfer of knowledge. The United States has the largest number of works (177) and the highest number of citations (3926) and the largest number of cooperative works (99). Followed by Canada with 36 cooperative works, and France with 30 (Table 1).

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Table 1. Ranking of the top 10 countries that work the most in cooperation.

Countries	Number of articles	Citations	Articles in cooperation[1]
United States	177	3926	99
Canada	33	1521	36
France	27	497	30
China	26	192	29
England	47	677	25
Belgium	21	369	24
Taiwan	24	241	24
India	22	136	22
Netherlands	20	211	19
Germany	39	498	17

[1] are scientific articles co-authored showing the scientific cooperation between authors from different institutions and nationalities. Source: Based on processed data by the authors

4.3 Articles, authors, and journals

To substantiate the relevance of publications based on scientific articles, Table 2 displays the first 10 articles, authors and their respective journals with their respective citations and average citations per year. The largest number of citations (1088) is represented by the effort of a group of 14 authors, in an article published in the Nucleid Acids Research Journal, in 2011. The research refers to the DrugBank database, with information on bioinformatics and chemo-informatics, which combines detailed drug data with comprehensive information on possible drug targets. In second, is the Management Science journal, published in 2007, with the second highest number of citations (515).

Table 2. Ranking of the first 10 articles with the respective citations

Authors	Journal	Citations	Average Year
Knox, C.; Law, V.; Jewison, T.; Liu, P.; Ly, S.; Frolkis, A.; Pon, A.; Banco, K.; Mak, C.; Neveu, V.; Djoumbou, Y.; Eisner, R.; Guo, A.; Wishart, D. [41]	Nucleic Acids Research	1088	120.89
Schilling, M.; Phelps, C. [42]	Management Science	515	39.62
Zucker, L.; Darby, M.; Armstrong, J. [43]	Management Science	438	24.33
Giddings, G.; Allison, G.; Brooks, D.; Carter, A. [44]	Nature Biotechnology	323	16.15
Baylis, A. [45]	Pest Management Science	276	13.8
Gittelman, M.; Kogut, B. [46]	Management Science	274	16.12
Blumenthal, D.; Causino, N.; Campbell, E.; Louis, K. [47]	New England Journal of Medicine	220	9.17
Ziedonis, R. [48]	Management Science	215	13.44
Shane, S. [49]	Management Science	196	10.89

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Broothaerts, W.; Mitchell, H.; Weir, B.; Kaines, S.; Smith, L.; Yang, W.; Mayer, J.; Roa-Rodriguez, C.; Jefferson, R. [50]	Nature	161	10.73

Source: Based on processed data by the authors

4.4. Journals, articles, and citations

We conducted a joint analysis of the number of publications, the number of citations related to journals (Table 3), since traditionally the evaluation of the number of published works, initially widely accepted and used, is no longer sufficient as a way of assessing the vigor of the scientific production. The quality of publications is also seen as a differential factor. Thus, the evaluation of the interest aroused by the work or line of research within the scientific community is highlighted, a factor that reflects the number of citations made to a given work [51] and where published. The Management Science, Scientometrics, Nature Biotechnology, and Technovation journals have the highest citation rates and the largest number of articles.

Table 3. List of journals, articles, and citations

Journals	Number of citations	Ranking citations	Number of articles	Ranking Articles
Management Science	1802	1	10	9
Nucleic Acids Research	1156	2	2	50
Scientometrics	768	3	51	1
Nature Biotechnology	403	4	11	7
Technovation	369	5	14	5
Management Science	301	6	1	91
New England Journal of Medicine	225	7	1	92
Nature	188	8	3	34
Biotechnology and Bioengineering	156	9	2	51
Journal of Product Innovation Mgmt	139	10	2	52

Source: Based on processed data by the authors

4.5. Countries and institutions

Observing how countries, institutions, and authors relate in network with the respective nodes and edges, it was found that level 1, the nodes are the authors, and the edges the scientific articles produced in co-authorship. Level 2 is the nodes represented by the institution to which the authors are linked, and the edges are the scientific articles produced in co-authorship. In level 3 we have the country to which the authors belong, and the edges are the institutions where the scientific articles in co-authorship are produced (Figure 2).

The structural position of actors within a network is an important indicator of their ability to articulate with other actors, as well as their ability to openly seek innovation [52,53]. The centrality that an actor has within a network system demonstrates its importance or prominence individually in the formed network [54,55]. In the field of innovation studies, actors with high centrality can be considered the most "open innovators" in innovation systems or knowledge networks [56].

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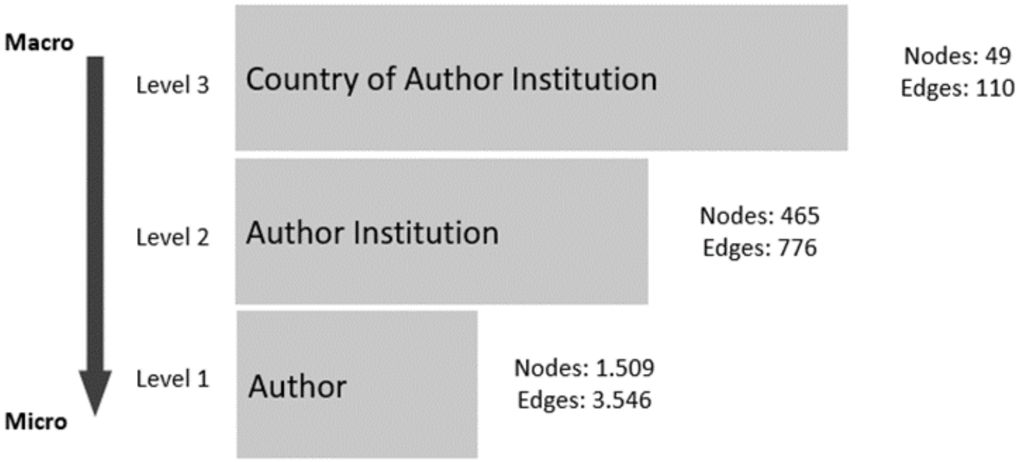

Figure 2. *Granularity Map. Source: Based on processed data by the authors*

The United States forms a great hub, the country concentrates its research and correlates with practically the whole world, with highlight from the intense cooperation formed by Belgium, England, Germany, China, and Canada. The sub-hub that Saudi Arabia forms with other countries in the Middle East is noteworthy. This empowers this country a lot regarding knowledge about patents and biotech. We highlight the clusters of Holland and Spain, which in a way, shows the affinity of cooperation (and possibly knowledge) between these different countries. The detailed ranking of 15 main countries that have the largest publications, confirm that strength of The United States is unambiguous, as they include the largest number of articles and the largest number of citations followed by countries have already identified in the network (Table 4).

Table 4. Ranking of countries, publications, and citations

Country	Number of citations	Ranking citations	Number of Articles	Ranking articles
USA	4498	1	177	1
Canada	1572	2	33	4
England	722	3	47	2
Germany	526	4	39	3
Italy	500	5	29	5
Wales	396	6	5	21
Belgium	378	7	21	10
Taiwan	260	8	24	8
Australia	245	9	14	13
Spain	243	10	11	16
France	240	11	26	6
Netherlands	218	12	20	11
China	210	13	26	7
Brazil	191	14	20	12
India	147	15	22	9

Source: Based on processed data by the authors

Table 5 shows the distribution of scientific articles made in cooperation by the authors in each country, with other institutions in the same country, or with another institution in different countries, indicate that a “local cooperation." In table, “local” means that the cooperation took place in the same country and at the same university, “national”

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refers to the cooperation between researchers took place in the same country, but in different universities. And "International", it means that the cooperation between researchers took place in different countries and, consequently, in different universities.

Table 5. Ranking of countries

Country	International	%	National	%	Local	%	Without Cooperation	%	Total
USA	35	0.20	37	0.24	43	0.21	62	0.35	177
England	15	0.32	12	0.02	1	0.26	19	0.40	47
Germany	10	0.26	8	0.23	9	0.21	12	0.31	39
Canada	9	0.27	8	0.24	8	0.24	8	0.24	33
Italy	10	0.34	6	0.21	6	0.21	7	0.21	29
China	7	0.27	9	0.31	8	0.35	2	0.08	26
France	7	0.27	5	0.23	6	0.19	8	0.31	26
Taiwan	3	0.13	9	0.33	8	0.38	4	0.17	24
India	3	0.14	11	0.14	3	0.50	5	0.23	22
Belgium	11	0.52	8	0.05	1	0.38	1	0.05	21
Netherlands	9	0.45	2	0.10	2	0.10	7	0.35	20
Brazil	4	0.20	8	0.35	7	0.40	1	0.05	20
Australia	2	0.14	4	0.07	1	0.29	7	0.50	14
Switzerland	1	0.25	1	0.08	2	0.33	8	0.33	12

Source: Data analysis was conducted by the authors using Gelphi software

In terms of percentage, The United States leads again the ranking with 177 scientific articles, 35% without cooperation, 21% local cooperation, 24% national cooperation, and 20% international cooperation. The country with the highest of international cooperation in percentage is Belgium (52%). While the Japan has the largest number of articles without cooperation (67%).

4.6. Institutions

Table 6 demonstrates articles distribution among institutions (universities). The University of Alberta, Canada, is first in the number of citations and in thirteenth position in the ranking of articles. However, Katholieke Leuven University, in Belgium, is the first university in the ranking of articles with 13 publications, occupying the nineth position in the number of citations.

Table 6. Ranking of institutions

Universities	Country	Citations	Articles	Ranking Articles	Citations Articles	Ranking Citations Articles
Univ. Alberta	Canada	1168	4	13	292.0	6
Natl Inst. Nanotechnol	Canada	1120	1	116	1120.0	1
New York University	USA	832	3	24	277.3	7
Univ. Washington	USA	552	1	117	552.0	2
Univ. Calif. Los Angeles	USA	509	3	25	169.7	10
Anal Grp Econ	USA	449	1	118	449.0	3
Harvard University	USA	443	5	7	88.6	18
University of Wales	Wales	375	1	119	375.0	4
Katholieke Univ. Leuven	Belgium	348	13	1	26.8	101

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University of Penn	USA	315	2	47	157.5	11
Zeneca Agrochem	England	301	1	120	301.0	5
University of Minnesota	USA	278	6	4	46.3	40
University of Michigan	USA	238	5	8	47.6	37
Massachusetts Gen. Hosp.	USA	225	1	121	225.0	8
University of Maryland	USA	213	2	48	106.5	17

Source: Data analysis was conducted by the authors using Gelphi software

Table 7 shows the level of cooperation. The universities in Belgium and England do all their research in cooperation. In the case of the University of Belgium, 46% of its research is either local or international. We highlight the dynamics of American universities, which are on this list, all working in some way in international cooperation, except for the universities of Missouri and, surprisingly, Harvard. Asian universities stand out, with four universities represented on the list.

Table 7. Ranking of cooperation among universities

Author affiliation	Country	International	National	Local	Without cooperation	Total
Katholieke Univ. Leuven	Belgium	0.46	0.08	0.46	0.00	13
University SUSSEX	England	0.13	0.00	0.88	0.00	8
Duke University	USA	0.43	0.39	0.14	0.14	7
University of Minnesota	USA	0.50	0.33	0.00	0.17	6
Natl Taiwan University	Taiwan	0.50	0.00	0.50	0.00	6
University of Missouri	USA	0.00	0.33	0.00	0.67	6
University of Michigan	USA	0.20	0.00	0.00	0.80	5
Norman Consulting	England	0.00	0.00	0.00	1.00	5
Tufts University	USA	0.20	0.60	0.00	0.20	5
CNR	Italy	0.60	0.40	0.00	0.00	5
Harvard University	USA	0.00	0.40	0.20	0.40	5
Foley & Lardner	USA	0.40	0.00	0.20	0.40	5
Natl University Singapore	Singapore	0.50	0.35	0.00	0.35	4
Natl Cheng Kung University	Taiwan	0.25	0.35	0.25	0.25	4
Natl Yang Ming University	Taiwan	0.00	0.75	0.00	0.25	4

Source: Data analysis was conducted by the authors using Gelphi software

4.7. Network Analysis - metrics

To expand the analysis of this study, the authors used the indicators of modularity, degree, weighted average degree, degree of intermediation, degree of proximity, giant component, and PageRank, with the intention of contributing to the analyses and findings necessary to respond to the research problem.

According to Blondel et al. [57], the modularity metric is the most used to identify cooperation clusters. This metric has an algorithm that makes it possible to group nodes that are more densely connected than in the rest of the network and that define communities according to the strength of their connections.

Therefore, once the network is defined with its nodes and edges, there is a wide variety of metrics that can be used to evaluate not only the elements (composition) of a network, but also the way they behave when interconnected. The main algorithms and functions used in SNA and adopted in this work are degree centrality [36,58], closeness centrality [58], betweenness centrality [36], PageRank [59], and eigenvector centrality [60].

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Table 8 shows all network statistics extracted from Gephi software and treated with Excel resources for the top 15 countries.

Table 8. Ranking of cooperation among universities

Country	Degree	PageRank's	Eigenvector centrality	Triangles	Clustering Coefficient
USA	25	0.102	1	33	0.110
England	11	0.043	0.546	15	0.273
Saudi Arabia	13	0.042	0.703	28	0.359
Germany	9	0.040	0.413	7	0.194
Belgium	10	0.039	0.538	16	0.356
Italy	10	0.037	0.579	14	0.311
Netherlands	6	0.025	0.388	8	0.533
Denmark	6	0.024	0.377	7	0.467
Iran	8	0.024	0.530	22	0.786
Canada	5	0.023	0.251	2	0.200
China	5	0.021	0.277	4	0.400
France	5	0.021	0.304	4	0.400
Bahrain	7	0.021	0.416	21	1.000
Jordan	7	0.021	0.416	21	1.000
Kuwait	7	0.021	0.416	21	1.000

Source: Data analysis was conducted by the authors using Gelphi software

The United States is the country with the largest representation within the network formed, as they meet, among others, the following criteria: degree centrality, as it has significant representativeness in the network formed (25), demonstrates its popularity and ability to disseminate information influencing the connected countries with it in the network; eigenvector centrality represents how the country impact other actors in terms of the global or total network structure [60] and PageRank, which is an algorithm used in SNA with a similar function to the others of centrality is used to indicate the highly connection of the country with many other countries in the network. This data analysis may also be viewed in the network design (figure 3) and these associations may be applied for all countries listed on the table.

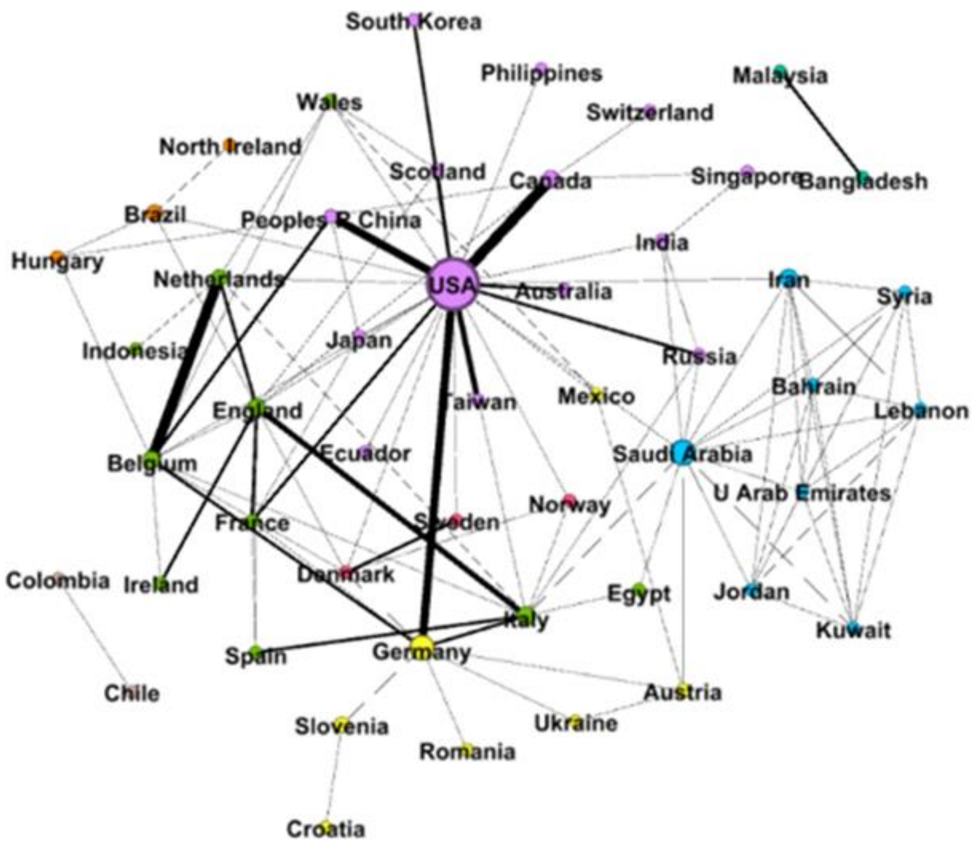

Figure 3. *Country network. Source: Data analysis was conducted by the authors using Gelphi software*

4. Discussion

This study analyzed the scientific production on the theme of technological cooperation networks and patents in biotechnology, based on bibliometrics with network analysis. We visualized how researchers, universities, and countries are strategically organized to conduct their research in the field of biotechnology.

Initially identify that the theme "technological cooperation networks" has been growing over the years and consolidating itself in the scientific literature, particularly in the biotechnology sector, where companies use cooperation to gain efficiency, especially in their R&D processes. In this arrangement, investments in R&D are an important tool to increase the innovative potential of an industry or region.

When policy makers provide support for research and development, they expect funded companies to reinforce additional investments in their own R&D, create new opportunities for mutual learning, aiming to increase the results of research and the innovative potential of companies [61]. This phenomenon occurs since there is a demand due to the sector's dynamics to be continuously launching innovative products.

The United States leads general scientific production, with 27% of the world's production. Second is England (7%), followed by Germany (6%) and Canada (5%). Regarding the number of citations, The United States remains the frontrunner with 39% of total number, Canada appears with 14%, England with 6% and Germany with 5%.

Another interesting aspect to note is the number of citations by the authors that stand out in their respective areas, as this is an indicator of productivity, as recommended by Lotka's law. In the technical area, Knox et al. [41] appears with 13 more researchers from the University of Alberta and 1088 citations. In the management area Schilling and Phelps [42] appears with 1377 citations, and Zucker et al. [43] with 1336 citations.

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In the analysis of cooperation networks between countries, The United States' role as the main hub in the publication of scientific articles related to the biotechnology field is clear. Concerning the field of studies on innovation, the actors with high centrality can be considered the most 'open innovators' [56]. The United States has a global strategic role, maintaining strong research connections from scientific articles in cooperation by its institutions with countries such as Canada, China, and Germany, among others.

In turn, Europe also forms a hub together with Germany as one of the most representative actors in this block, maintaining research connections with Italy, England, Holland, and Belgium countries. In this sense, the structural position of actors within these network systems is an important indicator of their capacity for open innovation [52,53].

From the analysis of the cooperation network between countries and universities, one can ascertain the strategy that each country adopts in the development of research in the field of biotechnology and The United States again leads with approximately 70% of its research developed in cooperation internationally (20%), nationally (24%) and locally (21%). These figures demonstrate a balance in North American participation. Germany and Canada have a similar balance. The exception is for England, which works with 60% of its research in a cooperative way, 32% internationally and only 2% nationally. Despite of this scenario, England strategy clearly demonstrated its open globally.

In cooperation among universities, seven American universities appear as highly cooperative institutions, three universities in Taiwan and two in England. And North America predominance is unmistakable, and the numbers are somewhat balanced.

We concluded that in the biotechnology sector naturally work in an environment in which network cooperation predominates, corroborating with findings of Casper [62]; Gay and Dousset [63]; Powell and Sandholz [64]. It means that R&D process can be performed more efficiently in a lowest possible cost and time. The path direction is in the search for new resources that complement skills and competences. Cooperation is also in favor of new knowledge acquisition and access to complementary resources [65], thus improving the allocation of investments and contributing to the innovative performance of the actors involved [66,67].

5. Conclusions

Under cooperative aspects, universities and research centers play an essential role in the process because the greater intensity of cooperation, the higher gains for all actors involved. The role of universities as knowledge transfer institutions is fundamental to innovation ecosystems, making the regions more representative in innovation field [55,68,69,70].

The study has some limitations in analyzing only a specific period. However, it would be interesting to evaluate other segments such as nanotechnology for future studies, in other regions identifying their characteristics and specificities.

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