A bibliometric exploration of the research activity behind COVID-19.

Journal:	*Big Data & Society*
Manuscript ID	BDS-21-0143
Manuscript Type:	Original Research Article
Keywords:	Bibliometrics, scientometrics, Covid-19, SARS-CoV-2, Machine learning, Algorithms
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2020 was characterized by the appearance of a new pandemic; COVID-19. This recent phenomenon is still ongoing, and much research has been carried out to find a solution. The statistical tools of machine learning (ML) and artificial intelligence (AI) have been heavily instrumental in advancing solutions against COVID-19. The current study uses a bibliometric approach to identify the main characteristics in the scientific research on COVID-19 relying on ML and AI tools. With a sample of 2639 documents recovered between January 2019 and January 2021, a total of 12093 authors were identified, of which 267 developed individual authorships. Of the total number of documents obtained, 35 book chapters, 295 conference papers, and a total of 1646 scientific articles were recovered. Additionally, the countries' collaboration network and the co-authorship network were identified, including thematic clusters related to the topic.

Keywords: Bibliometrics; scientometrics; Covid-19; SARS-CoV-2; Machine learning; Algorithms; Statistics.

1. Introduction

In December 2019 in Wuhan, the capital of Hubei Province in mainland China, a new virus called SARS-CoV-2 or COVID-19, as it is commonly known, appeared (Zhou et al., 2020). COVID-19 brings with it a series of consequences for the population, including economic and physical losses, which have been devastating and regrettable, taking the lives of thousands of people and destroying many others (Liu et al., 2020).

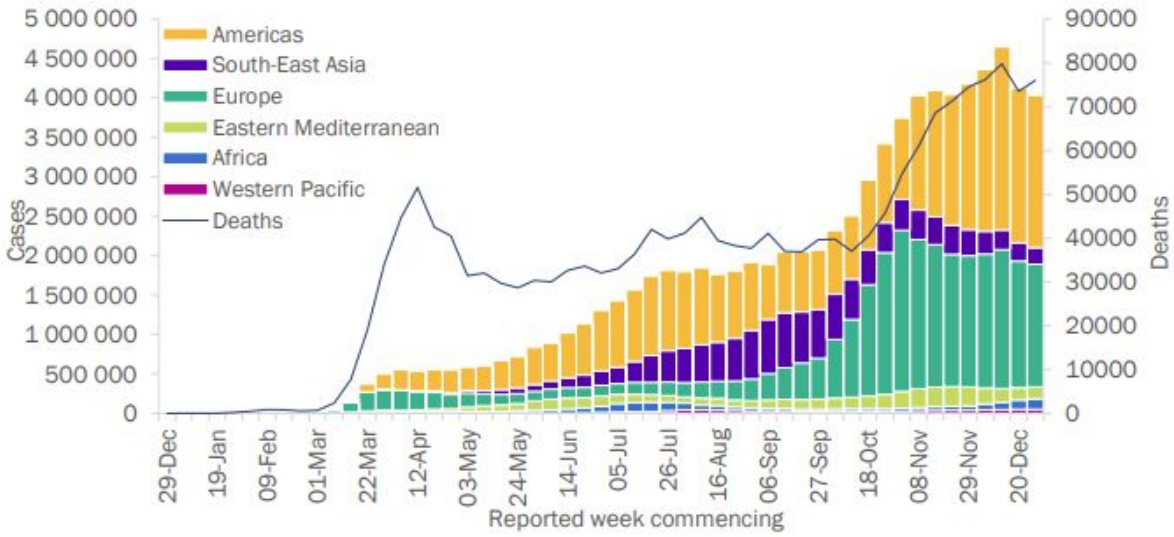
Thanks to scientific advances, the virus's genome was published on January 5, 2020, and on March 11, 2020, the virus was declared a global pandemic (Koirala et al., 2020). Thus, Covid-19 has become a significant challenge for nations worldwide, being one of the most challenging issues for humanity in the last 100 years (Hall et al., 2020). This virus has result in the affection of the world economy (Wang & Su, 2020), changing people's eating habits (Scarmozzino & Francesco 2020), their recreational habits, their exercise routines (Ruiz-Roso et al., 2020) and affecting the psychological stability of thousands of people (L'Angiocola & Monti, 2020).

The pandemic forced nations into routines that modified the habits of all human beings and many nations took desperate measures to stop the spread of the viruse. Italy decreed a lockdown in March 2, 2020 (L'Angiocola & Monti, 2020), Spain did so in March 14, Brazil did so in March 27, along with approximately 200 other nations that acted against the approaching situation (Ruiz-Roso et al., 2020; Wang & Su, 2020).

In multiple regions, the consequences of the presence of the virus were devastating. For example, there was a surge in the risk of increased alcohol consumption (Clay & Parker, 2020), domestic violence (Arenas-Arroyo, Fernandez-Kranz & Nollenberger, 2020), cases of violence against women (Viero et al., 2020) or the terrible misinformation and the public's susceptibility to rumors against vaccines, treatments, among others (Roozenbeek et al., 2020).

Figure 1 shows the weekly report by the OMS where, "for the third week in a row over 4 million new cases were reported globally, although this week saw a slight decrease compared to the previous week. However, this and other short-term trends in data should be interpreted with caution owing to the end-of-year holiday season, as numbers may be influenced by presentation, testing and reporting delays" (OMS, 2021, P. 1).

Figure 1. The COVID-19 weekly report by the OMS (OMS, 2021)



To tackle COVID-19, a global vaccination process is currently being initiated. This process has 10 vaccine candidates, which are part of the progress made so far (Koirala et al., 2020; Kabra & Singh, 2021). However, efforts to know more about the virus cannot stop, since research is the only door to solve this and possibly future dilemmas for humanity.

In this constant battle against the virus, artificial intelligence (AI) which encompasses machine learning (ML; Sebag, 2014; Friedrich et al., 2020) has been one of the flagship techniques in statistics for predicting mortality, critical events, and for the development of a vaccine to cope with the disease (Vaid et al., 2020). There are many areas of intervention to address the pandemic, including mental health (Liu et al., 2020; Li et al., 2020), biology,

chemistry, medicine and many other areas in which AI and ML algorithms have been applied (Yang et al., 2020; Raza, 2021; Kabra & Shigh, 2020; Stebbing et al., 2020).

The multidisciplinary nature of the research behind COVID-19 represents the work of different professions with the same goal. For this reason, science does not have the character of a homogeneous system but is composed of a multitude of disciplines and subdisciplines, which makes it necessary to identify the changes in these areas around a specific topic (Kronegger et al., 2011). The area of knowledge that is dedicated to collecting this knowledge is called bibliometrics, which is a quantitative technique that allows the measurement of scientific activity on specific topics in specific periods (Mela et al., 2003). This technique allows identifying patterns within the different thematic circles of science, collaborative networks among authors, intervening countries, among many other characteristics of the way science behaves (Aria & Cuccurullo, 2017).

Based on the above, in the present paper we resort to bibliometrics (Garfield, 1972; Garfield, 2006) to characterize how research around COVID-19 has been behaving. In particular, the interest is in depicting the use of technologies such as AI or ML in COVID-19 research. Additionally, through bibliometry we identify international research networks' patterns on COVID-19 (Beskaravainajaa & Kharybinaa, 2020).

2. Research acquisition and methods.

Scopus is one of the largest scientific databases globally, providing a complete vision of the world's research production in the fields of science, technology, medicine, social sciences, arts and humanities. Due to these holistic characteristics, Scopus is selected as the source used for the analysis in this study (Jia, Zhou & Allaway, 2018).

On the other hand, it is crucial to consider that a large part of the world's literary production is developed in the English language, which is why searches are carried out in that language.

The literary search process aims to recover all documents with terms included in the following search algorithm: "coronavirus" OR "Covid" OR "Covid-19" OR "SARS-Cov 2" AND "machine learning" OR "artificial intelligence" OR "computational learning" OR "algorithms."

Searches were performed within titles, abstracts or keywords. Based on this search, on January 5, 2021, a total of 2785 results were identified. The first article recovered was published in 1975, however, considering that the year 2019 was the date of appearance of the virus (Zhou et al., 2020), 2639 documents published from 2019 to 2021 were retained. The information exported from these articles for analysis includes metadata, author information, keywords, references and citations.

The database obtained is analyzed using the software "Rstudio" (RStudio Team 2020, v. 4.0.3) using the bibliometrix and biblioshiny packages (Aria & Cuccurullo, 2017). Additionally, the GIMP 2.10.20 software is used to improve some of the graphics obtained. The database and R codes used to analyze the data are available at: https://github.com/psicorivera4/Covid-Bmtry

3. Bibliometric analyses

According to Khanra et al. (2021), the criteria of scanning, curating and reporting samples, were considered a first stage developing this document. In those stages the search for terms and search algorithm were developed, and a selection of the most appropriate documentation for the purpose of this study was carried out (Xu et al., 2018).

Table 1. *Main information about data.*

Description	Results
Timespan	2019:2021
Sources (Journals, Books, etc.)	1255
Documents	2639
Average mean citations per documents	3,806

References	85488
articles	1646
book chapters	35
conference papers	295
conference reviews	51
data papers	7
editorials	102
erratum	8
letters	126
notes	83
reviews	273
short surveys	13
Authors	12093
Author Appearances	14680
Authors of single-authored documents	267
Authors of multi-authored documents	11826
Single-authored documents	343
Documents per Author	0,218
Authors per Document	4,58
Co-Authors per Documents	5,56
Collaboration Index	5,15

Thus, a total of 2639 documents were obtained, with a total of 12093 authors, of which 267 developed individual authorships. Of the total number of documents obtained, 35 book chapters, 295 conference documents and a total of 1646 scientific articles were recovered (see Table 1).

On the other hand, the development and identification of production at a global level is something fundamental, since it allows to verify the scientific collaboration networks between countries, facilitating universities and researchers to get an idea of how the collaboration networks are working (Zareia, & Jabbarzadeha, 2019).

Figure 2. Country scientific production.

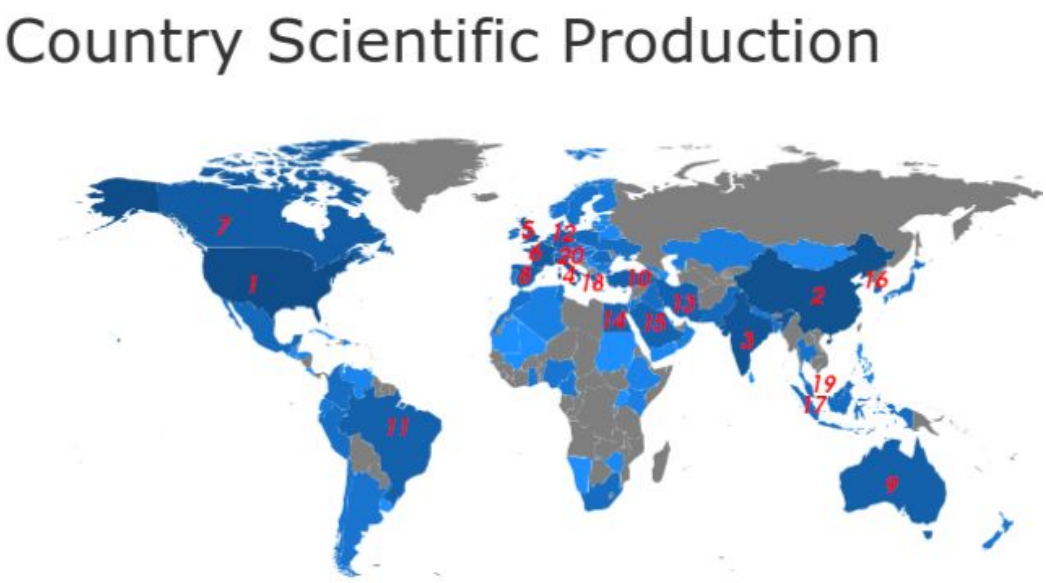


Table 2. Twenty most productive countries in the world.

	region	Freq
1	USA	1829
2	CHINA	1172
3	INDIA	709
4	ITALY	664
5	UK	577
6	FRANCE	306
7	CANADA	300
8	SPAIN	227
9	AUSTRALIA	214
10	TURKEY	181
11	BRAZIL	176
12	GERMANY	167
13	IRAN	152
14	EGYPT	140
15	SAUDI ARABIA	122
16	SOUTH KOREA	120

17	SINGAPORE	84
18	GREECE	80
19	MALAYSIA	73
20	SWITZERLAND	73

In this document, information has been obtained from the 20 most productive countries, with the United States, China, India, Italy, UK, France, Canada, Spain, Australia and Turkey being the 10 countries with the highest literary production in the field (see Table 2; this information can be mapped onto Figure 2).

However, knowing the list of the most productive countries in the field is not enough information for science, because the scientific conglomerate uses collaborative networks (Shen et al., 2018). Based on this postulate, Figure 3 shows the collaborative networks between countries. This information can be contrasted more clearly in Table number 3, which shows the collaborative networks according to the number of documents produced and the strength of the collaborations.

Figure 3. Country collaboration network.

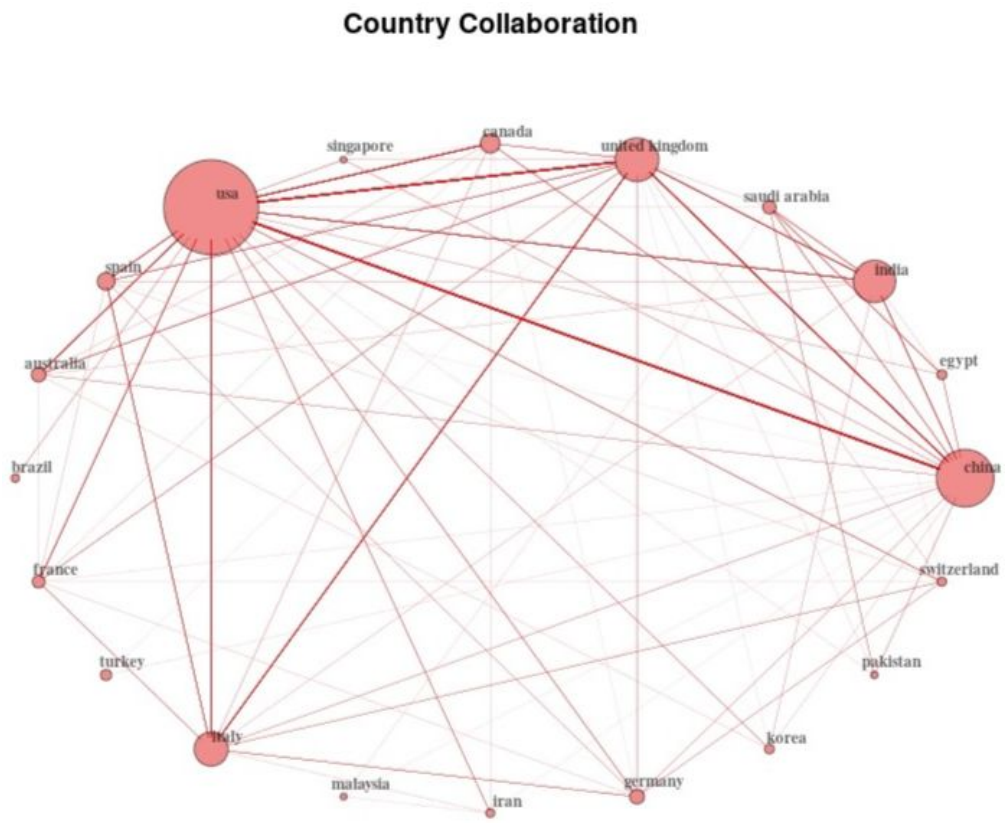


Table 3. Collaboration networks, frequency of publication and direction.

From	To	Frequency
CHINA	USA	68
UK	USA	62
USA	ITALY	47
CANADA	USA	31
CHINA	UK	30
UK	ITALY	27
INDIA	USA	23
USA	AUSTRALIA	23
INDIA	UK	22
CHINA	HONG KONG	19
USA	SPAIN	19
CHINA	INDIA	18
SPAIN	ITALY	18
USA	FRANCE	18

EGYPT	SAUDI ARABIA	15
INDIA	SAUDI ARABIA	15
UK	AUSTRALIA	15
UK	SPAIN	15
CHINA	CANADA	14
CHINA	SAUDI ARABIA	14
UK	CANADA	14
USA	SWITZERLAND	14
ITALY	GERMANY	13
USA	GERMANY	13
USA	IRAN	13
CHINA	EGYPT	12
CHINA	JAPAN	12
FRANCE	ITALY	12
UK	FRANCE	12
ITALY	SWITZERLAND	11
SAUDI ARABIA	PAKISTAN	11
SINGAPORE	USA	11
USA	KOREA	11
CHINA	AUSTRALIA	10
CHINA	ITALY	10
CHINA	PAKISTAN	10
CHINA	SINGAPORE	10
GERMANY	SWITZERLAND	10
UK	GERMANY	10
USA	BRAZIL	10
USA	ISRAEL	10

Additionally, collaborative networks index the way in which the authors form networks of participation through co-authorship. An author collaboration network can be obtained using the general formula AC=AT×A where "*A"* is a bipartite network Manuscripts and "AT" stands for Authors. The diagonal element "ACi" is the number of manuscripts authored or co-authored by researcher "*i"* (Aria & Cuccurullo, 2017).

Figure 4 shows four collaboration clusters; the first collaboration in violet, the second one in red, then one in green and finally one in blue. Each of the clusters refers to different collaborative networks, where the nodes represent the author with his degree of importance and the links between them represent the co-authoring networks (Glänzel, 2004).

Figure 4. Collaboration network.

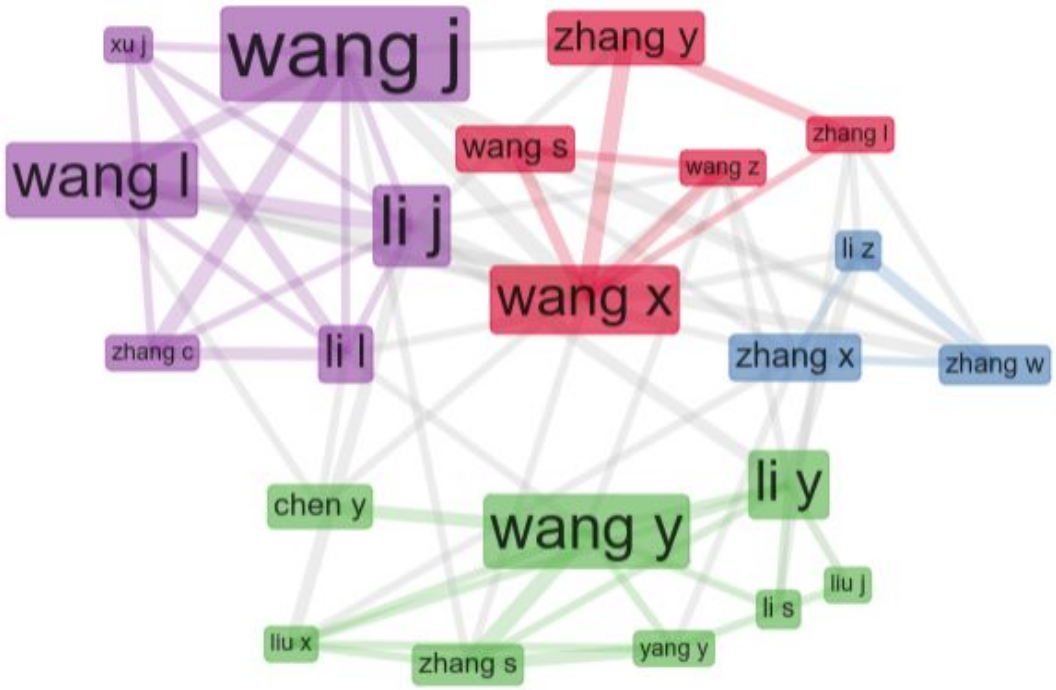


Table 5 shows the most cited documents in the topic (Aria & Cuccurullo, 2017). This table reports the first four authors of the document, the year of publication, the title of the document and the journal in which they were published.

Table 5. Top 8 most cited documents.

	Authors (first 4.)	Title + Doi	Journal	Total citations
1	Luca Ferretti Chris Wymant Michelle Kendall Lele Zhao	Quantifying SARS-CoV-2 transmission suggests epidemic control with digital contact tracing. DOI:10.1126/science.abb6936	Science	333
2	Liu, S Yang L Zhang C Xiang, Y.-T	Online mental health services in China during the COVID-19 outbreak https://doi.org/10.1016/S2215-0366(20)30077-8	Lancet Psychiatry	327
3	Justin Stebbing Anne Phelan Ivan Griffin Catherine Tucker	COVID-19: combining antiviral and anti-inflammatory treatments. https://doi.org/10.1016/S1473-3099(20)30132-8	Lancet Infect	322

4	Sijia Li Yilin Wang Jia Xue Nan Zhao	The Impact of COVID-19 Epidemic Declaration on Psychological Consequences: A Study on Active Weibo Users https://doi.org/10.3390/ijerph17062032	International Journal of environmental research and public healt	197
5	Zifeng Yang Zhiqi Zeng Ke Wang Sook-San Wong	Modified SEIR and AI prediction of the epidemics trend of COVID-19 in China under public health interventions. http://dx.doi.org/10.21037/jtd.2020.02.64	Journal of Thoracic Disease	192
6	Daniel Shu Wei Ting Lawrence Carin Victor Dzau Tien Y. Wong	Digital technology and COVID-19 doi:10.1038/s41591-020-0824-5	Nature Medicine.	129
7	Lin Li Lixin Qin Zeguo Xu	Using Artificial Intelligence to Detect COVID-19 and Community-acquired Pneumonia Based on Pulmonary CT: Evaluation of the Diagnostic Accuracy 10.1148/radiol.2020200905	Radiology	127

8	Youbing Yin Federica Ciccarese Francesca Coppola Daniele Spinelli Giovanni Luca Galletta	Diagnostic Accuracy of North America Expert Consensus Statement on Reporting CT Findings in Patients with Suspected COVID-19 Infection: An Italian Single Center Experience	0.1002/jum.15285	Radiology: cardiothoracic imaging	127
9	Roberto Fumagalli Stefano Spina Francesco Marrazzo Maurizio Migliari	The response of Milan's Emergency Medical System to the COVID-19 outbreak in Italy.	https://doi.org/10.1016/S0140-6736(20)30493-1	Lancet	113
10	Tulin Ozturk	Automated detection of COVID-19 cases using deep neural networks with X-ray images.		Computers in Biology and Medicine	109

Muhamme	https://doi.org/10.1016/j.compbiomed.2020.10
d Talo	3792
Eylul Azra	
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Rajendra	
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On the other hand, this database analysis focuses on the statistical tools and concepts referred to in studies on COVID-19 (Mariani & Zenga, 2021). For this purpose, K-means and MCA for conceptual structure maps (Aria & Cuccurullo 2017) are used.

Figure 5. Conceptual structure map

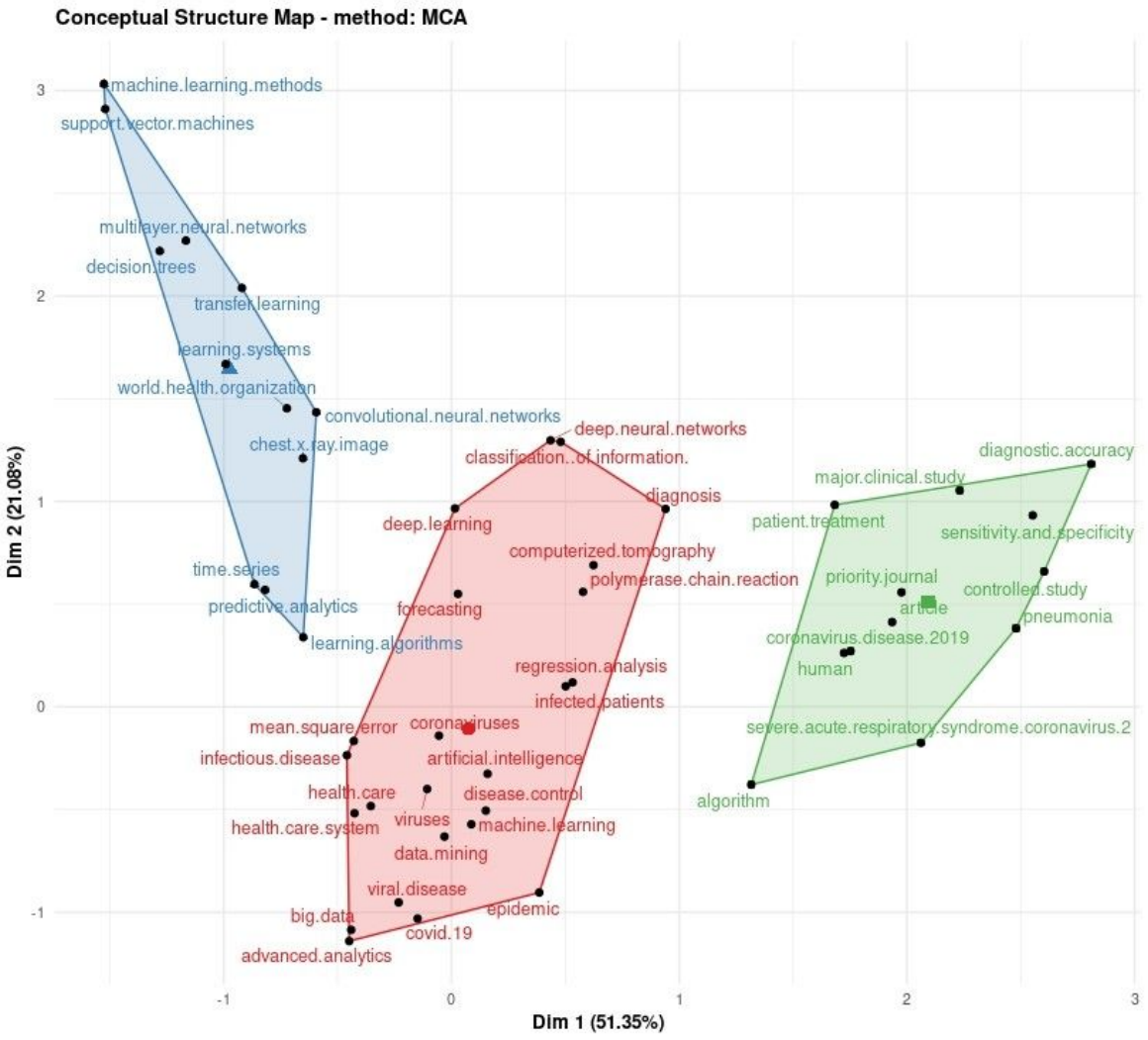

Figure 5 shows how the themes are grouped within the compendium of documents, highlighting the presence of three major thematic clusters. In each of the clusters, a series of topics are observed, which are grouped by frequency of repetition of such topics in the documents analyzed. In addition, the thematic proximity in each cluster is evident since the topics are located in a Cartesian plane.

Figure 6.

Thematic dendrogram.

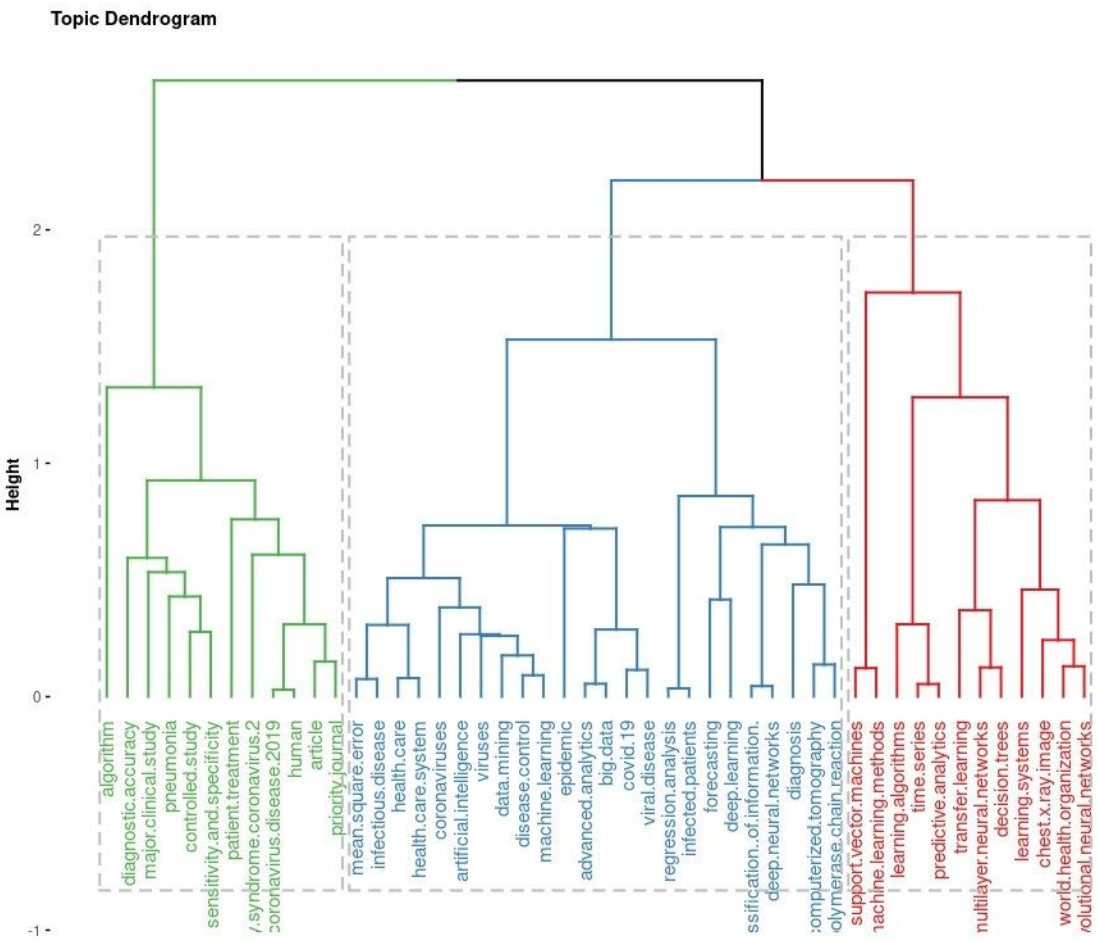

Figure 6 presents a thematic dendrogram indicating how the themes are grouped into clusters and the relationship between these clusters. This figure allows visualizing the relationship and strength of the various themes.

There are three dominant thematic clusters. The red cluster and the blue cluster have a greater degree of proximity than the green cluster. This situation has a certain correspondence with the themes grouped by the clusters, since the green cluster has a medical domain, and the blue and red clusters have a greater dominance of mathematical-algorithmic themes.

4. Discussion

Bibliometric techniques (Garfield, 1972; Garfield, 2006) were used to characterize the way science around COVID-19 behaves. In particular, the interest is in depicting the use of technologies such as AI or ML in COVID-19 research. This document has made possible to

show three fundamental aspects: First, a general analysis of the scientific production, identifying the number of documents produced up to the date of writing this article, the most popular type of document, the number of authors involved in the publications, among other important aspects. In addition, the scientific trend concerning the countries involved in this process, their direction and their publication capacity has been evidenced. Lastly, an analysis of the most popular authors, journals and topics has been developed, showing which are the journals with the most cited articles and grouping topics in clusters according to their proximity and popularity.

The organization of scientific topics has never been more critical than now, given that, with the appearance of tools such as the Internet, the grouping of scientific topics is becoming more complicated (Aria & Cuccurullo, 2017).

Humanity is in a race against time, in which the identification of technologies for detection, prevention and treatment of the disease represents thousands of lives to be saved (Raza, 2021). However, it is not only about identifying technologies for this purpose, since the adequate use of advanced technologies such as bibliometrix (Aria & Cuccurullo, 2017), allows the scientific community to identify trends in publication and research topics, as well as to expand collaborative networks (Beskaravainaja & Kharybinaa, 2020).

The topic dendrogram and the cluster analysis allows identifying the proximity and hierarchy of the different topics that currently dominate the subject of this document, as it is considered that it can serve as inspiration for the development of new and more current research, additionally, it is a useful tool to identify gaps in the scientific landscape that provide the possibility of innovation.

The present study also presents a review of the countries and authors that dominate the subject now, which serves to identify the collaborative networks in which science is currently moving, as well as, their direction and strength. This information has the possibility of

identifying the journals and areas of the world where knowledge is being accumulated, enabling new researchers to identify potential networks to join. The bibliometric analysis was performed in the canonical way literature reviews are performed. However, future systematic reviews (i.e. meta-analysis and literature reviews) should resort to open source technologies relying on ML to enhance efficiency and transparency (see Schoot et al., 2021).

In the last 100 years, the world has not experienced a similar situation (Hall & Prayag, 2020), as any effort to unify ideas and generate bonds of scientific collaboration for the benefit of humanity will be necessary. This document has the sole purpose of assisting in the development of such collaborative ties to forge an inter-institutional and interdisciplinary block for the development of a definitive cure for Covid-19.

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