A country-based review in COVID-19 related research developments

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Abstract:

The COVID-19 pandemic has turned our life topsy-turvy. It has bought a massive change in all sectors around the world. A great number of research papers have already been published accounting for various aspects of the COVID-19 issue, owing to the ever-increasing interest in this hot area. The essential data is gathered using the well-known and dependable search engine SCOPUS. We looked at research papers, journals, and reviews from 25 leading countries to highlight a comprehensive study of research output through COVID-19 papers. This study focuses on the top authors, leading articles, and journals from various nations, the percentage of published papers in various fields, and the top collaborative research work from different authors and countries. USA, U.K., China, Italy, and India have all made a significant contribution to COVID-19 research. The USA is the leading country followed by U.K. and China but for H-index China is in the best position. The highest number of papers has been developed in the area of 'medicine'. The Harvard Medical School of the U.K. contributed the highest number of papers followed by the University of Toronto of Canada. Professor K Dhama of India has published the highest number of papers while C. Huang of China received the highest number of citations. It also highlights that several authors have differing opinions on the efficacy of taking the medicine remdesivir. Our research provides a complete and comprehensive image of the virus's current research status, or in other words, a roadmap of the present research status.

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Keywords: *COVID-19; Pandemic; Research; Review; Country Analysis; Scopus*

1. Introduction:

The world is in disarray today as a result of the coronavirus's sudden attack. In December 2019, an epidemic of this lethal virus was reported in China's Wuhan city of Hubei Province. The virus spread fast over the world as a result of developed international communication. At the time of the virus's initial outbreak, countries like the United States of America (USA), Italy, France, Brazil, and the United Kingdom (U.K.) are in upheaval. Since its beginning in 2019, WHO recognized the fatal virus as COVID-19. This virus is most commonly referred to as coronavirus because of its crown-like structure. The virus poses a global health emergency throughout the world. To begin, practically most of the countries on Earth are being forced to go into lockdown day after someday to fight this lethal virus, as physicians or scientists are at a loss for how to combat it. Individuals are directed/asked to remain in their homes. The first wave of coronavirus killed a large number of people, including doctors, police officers, health care personnel, and teachers, as well as many ordinary citizens. This funeral procession was watched by the entire world. The coronavirus has a profound effect on social life and the environment. The world economy suffered tremendous damage as a result of the prolonged shutdown. Numerous businesses have ceased operations. The mode of transportation must be halted. As a result, a large number of people lose their work and become jobless. Many are compelled to switch jobs in order to survive. Work from home is a trend that began in the industry, information technology, education, and other sectors. So, researches have been started towards various sides like socio-economic, environment along with the discovery of medicine.

There are several bibliometric studies on COVID-19 publications. To the best of our knowledge, our study is the first one focusing on the contemporary COVID-19 literature depicting a comprehensive global research scenario. We have developed a country-wise review analysis of the current research status that emerged due to the sudden appearance of COVID-19. Su et al. (2021) presented a detailed and comprehensive bibliometric study providing research output of

various institutions, countries, scientists or physicians, etc. The objective of their study is to analyze the most cited papers as well as to find the research trend, and provide necessary information to the people. They reviewed 51047 papers, and in this matter, they rely on the Web of Science. According to their observation, The British Medical Journal is in a leading position in terms of publication but in terms of citations, The Lancet and New England Journal of Medicine is in the focus, and are in a better position. By the bibliometric study, Kappi et.al. (2021) would like to seek the research priorities highlighting top-cited publications, top-ranking institutes, top-contributing countries, top-publishing, top-citing, and top H-indexing journals, top-sub disciplines, top-language of research, etc., and so many aspects. They considered a total of 17333 different types of published articles from the web of science. According to their study, The British Medical Journal ranks first contributing 663 papers (3.87 % of the total publication) followed by the Journal of Medical Virology with 325 publications. The famous journal New England Journal of Medicine received the highest number of citations amounting to 5881 followed by The Lancet with 4780 citations and the Journal of American Medical Association (JAMA) has a total of 4634 citations. But in the light of the H-index JAMA occupies the second position with a 29 h-index and the journals New England Journal of Medicine and The Lancet have an h-index of 32 and 26 respectively. Keyword 'COVID-19' is mostly used with a total of 6180 in number followed by SARS-Cov-2 having 1926 times. The keyword 'coronavirus' appears 1570 times. The bibliometric study of Vasantha Raju et al. (2020) reflects that India is also playing an impressive role to enhance the progress of research on COVID-19. The authors framed their study based on the published papers on SARS-COV-2 using the WHO database as the data source. They observed that most of the researchers belong to either AIIMS or ICMR institutes. Indian Journal of Medical Research (IJMR) published a total of 14 papers within the time under consideration which is the highest in number. Epidemiology is the main focus of research. The keyword 'COVID' appeared 34 times followed by 'coronavirus' which occurs 23 times. Hossain (2020) presented a bibliometric analysis focusing on the application of artificial intelligence (AI) in COVID-19 research. They rely on the extensive data source 'MEDILINE' and considered 105 articles in this context. The primary purpose of AI is to promote equity. So, they try to find out the disparity in health, socio-legal issues, progress of vaccines, and practical public health research on COVID-19. According to their observation, there is tough competition between the USA and China concerning the publication of papers contributing 24, and 23 papers

respectively. Through a systematic review and meta-analysis, Rodriguez –Morales et al., (2020) attempted to offer an overview of clinical trials. They looked at more than 780 patients to observe risk factors like comorbidity, Intensive Care Unit (ICU) requirements, etc. They estimate that at least one-fifth of the admitted patients need ICU which is nearly impossible to provide for most countries. They considered the period between 01/01/2020-23/02/2020. Based on 172 studies, Chu et al. (2020) produced a systematic meta-analysis through which they examined the risk factors for the spread of COVID-19 infections. They observed that a 2-meter distance is optimum to mitigate the risk factor of infection. They also see that N-95 is more effective than the other masks. Wiersinga et al. (2000) developed a review that focuses on symptoms of infected patients, duration of exposure, the right time of diagnosis, and treatment among other things. They observed that 75% of hospitalized patients need oxygen support. They notice that remdesivir reduces the time it takes for patients who are discharged without oxygen. They emphasized the use of masks, maintaining social distancing, and tracing contacts. Ghadir et al. (2022) identified seventy different risks in a supply chain under seven categories due to the outbreak of COVID-19. Mondal & Roy (2021) developed supply chain models to retain supply among production centers and hospitals during the COVID-19 pandemic situation. Tirkolaee et al. (2022) presented a multi-period multi-echelon multi-product supply chain network of face masks during the COVID-19-pandemic. They used Multi-Objective Grey Wolf Optimization Algorithm and Non-Dominated Sorting Genetic Algorithm II to solve the proposed model and to find Pareto optimal solutions. Khalilpourazari et al. (2021) used a Gradient-based Grey Wolf Optimizer for modeling and prediction of the COVID-19 pandemic. AYDIN and Tirkolaee (2022) analyzed country-level growth dynamics of COVID-19. Babaee et al. (2021) presented a sustainable medical waste management policy under the COVID-19 pandemic situation.

In this paper, we present a bibliometric study on different aspects of COVID-19 which can highlight a complete picture of research status or progress on COVID-19. Health emergencies are going on all over the world due to the sudden occurrence of coronavirus, so there is a consensus on the progress of research on drugs or vaccines. By this study, it is possible to know which country is at which stage of research. Such type of study also analyses the effect on the social, economic, psychological, environmental, information technology, and industrial sectors. Though the medicinal field is in the leading position in terms of publication of covid related papers, other fields are also not far behind in this regard.

Scopus database is used for the collection of papers/articles as Scopus is a very well-known reliable source and contains a large dataset. The purpose of the present study is to explore the current research status of the deadly virus COVID-19. By this study, we have tried to comprehend which key realizations have been achieved to fight against the fatal virus. By this paper, we intend to highlight: (*i*) which countries are the leader in COVID-19 research? (*ii*) which author has published the highest number of papers? (*iii*) which authors have received a very good number of citations? (*iv*) how far research has been advanced in discovering fruitful medicine or vaccine around the world? (*v*) which institute has put special emphasis on research of COVID-19? (*vi*) which measures might be taken by the common people to save themselves from infection of the fatal virus? Here we have considered the papers based on the number of citations. Naturally, papers published in early 2020 have received more citations than the recently published papers. During that period there are no available medicines or vaccines in the world. Thus, the consciousness and carefulness of the people were very important at that stage. (*vii*) how much this calamitous situation has globally impacted other sectors like socio-economic, education, business, environment, etc. (*viii*) is there any sector which is not covered by the research that means is there any gap in research? (*ix*) is there any mediator for escalating/accelerating the infection? (*x*) since most of the papers considered here included clinical trials, real case studies of confirmed infected patients of different hospitals separately considering male and female, the study can delineate which sex are mostly infected by the COVID-19 or what steps may be adapted after recovery from the disease?.

The rest of the paper is arranged as follows: Section 2 discusses the methodology. Section 3 discusses Mathematical expressions and corresponding graphical representation of Covid-19 infections in the top six countries. The result as well as the necessary discussion is provided in Section 4. Major findings are presented in Section 5. Finally, a comprehensive conclusion is presented in Section 6.

2. Methods:

The well-known database SCOPUS is used to collect data for this study. It is a universally accepted and consistent database for scientific publications. SCOPUS covers 22,794 active titles and 13,583 inactive titles in its database. When searching for documents that had used "COVID-19" in the title or abstract or keywords, SCOPUS' search engine revealed a total of 207854 documents up to 14th October 2021. We limit the search result to English language and Journal publications. Next, we limit the search result to document types "article", and "review". In this way, we arrived at a total of 143686 documents (122465 articles, and 21221 reviews) for this study. Details of the article selection procedure are given in the Figure 1. A document will be considered for a country if one or more authors used affiliation of that country. Suppose a document has N authors from M different countries then it will be considered in the account of all M countries associated with its authors. Thus, a document may be possible to display in the account of more than one country. Based on the final data set of 143686 documents we find the leading twenty-five productive countries in COVID-19 research.

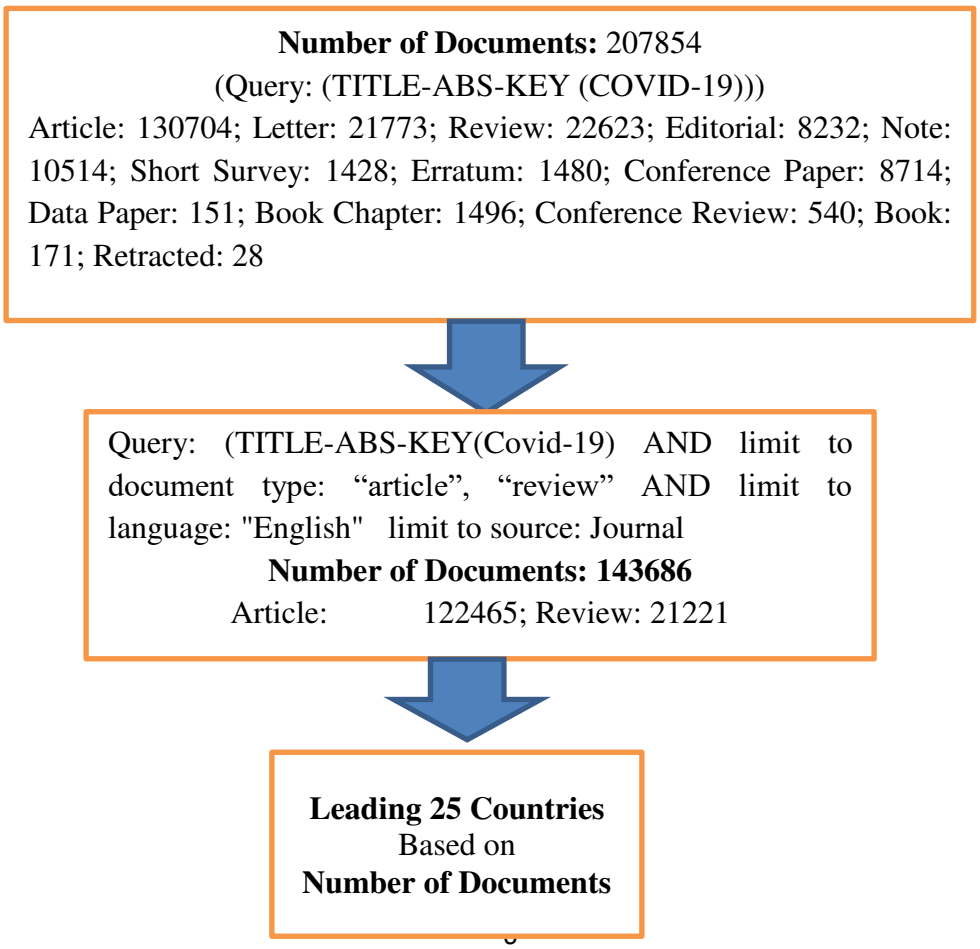


Figure 1. Document Selection Procedure.

Country-wise collected data are arranged and classified based on different indicators like the total number of publications (TP), H-index, and citation thresholds for 50, 100, 200, 500, and 1000 citations. A country has X number of publications and we have arranged contributing authors, institutions, and keywords based on those X publications. Thus, it may be possible that an author/institution can lead in a profile for a different country if it has strong collaboration with authors/institutions of that country. In this study, we also highlight frequently used keywords for the leading countries to explore research directions on COVID-19-related issues.

3. Mathematical expressions and corresponding graphical representation of Covid-19 infections in the top six countries

More than 230 countries in the world have more or less been affected by the calamitous virus. According to the world o meter as of 30th June, 2021 more than 182 million people are infected and the death toll is more than 3.9 million. The countries USA, India, Brazil, France, Russia, and Turkey secure the first six ranks from the top. The countries the USA, Brazil France had been attacked all of a sudden in the midway of February 2020.

Graphical Representation of number of infections of top six countries

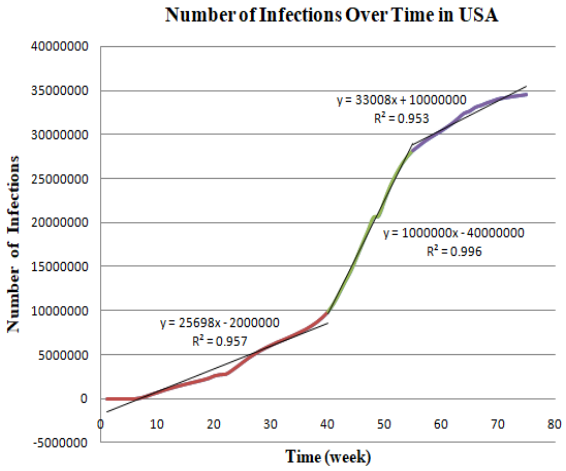
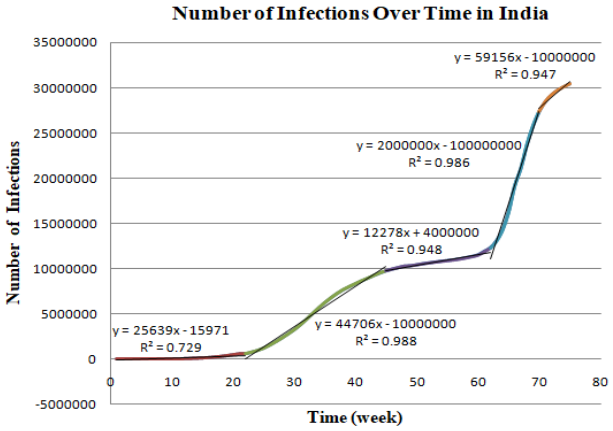


Figure 2



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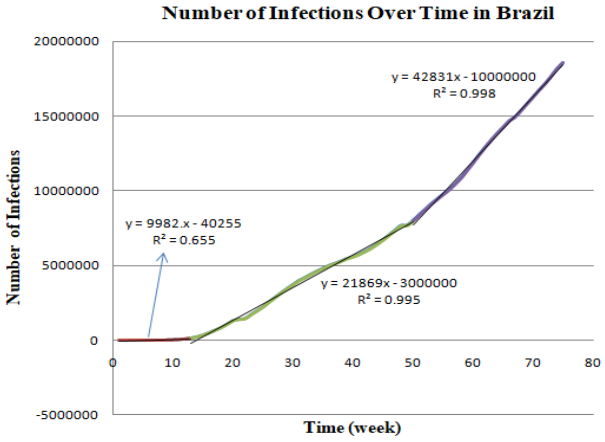

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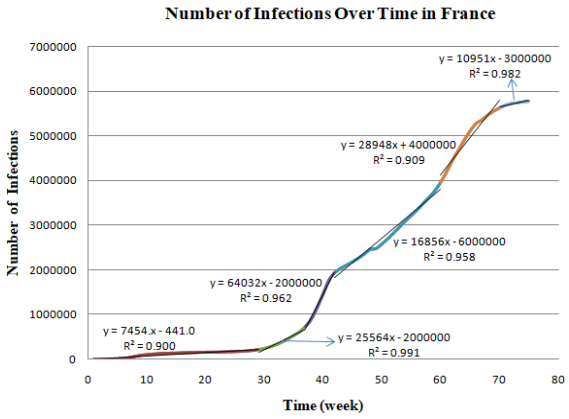

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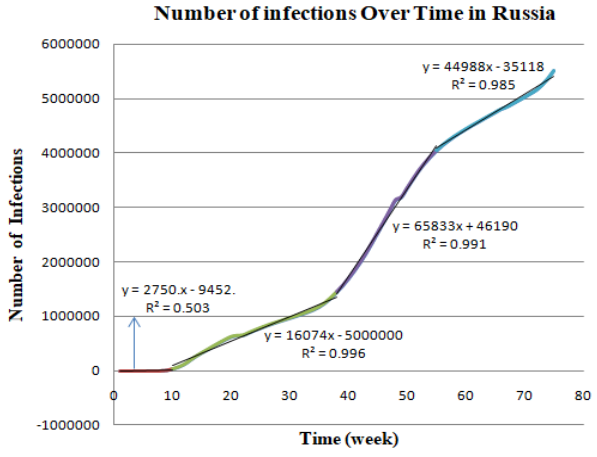

Figure 6

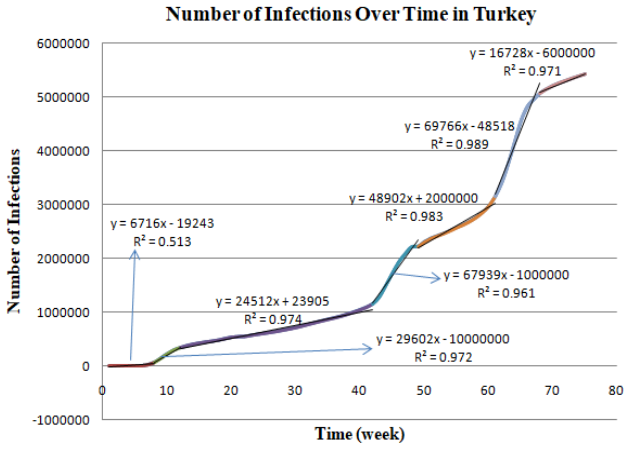

Figure 7

We have fitted the infected curve with three trend lines (straight lines) in the case of the USA (see Figure 2). The equations of the trend lines are

$y = 25698x - 2000000;\ y = (1000000)x - 40000000;$ and $y = 33008x + 10000000.$

It is observed that between 40 to 58 weeks (04/11/2020 to 05/03/2021) the gradient of the straight lines is nearly four times the same between 9 to 40 weeks (11/04/2020 to 28/10/2020) in the case of the USA. In India, five straight lines (see Figure 3) are needed to capture the graph of the number of infections. The equations of the trend lines are shown in Figure 2. We observe that in India, between 62 and 70 weeks (02/04/2021 to 26/05/2021) the trend line is steeper than the others. That means the number of infections rapidly increases in this time interval. The number of infections in Brazil has been fitted by three-line segments (see Figure 4), which are

$$y = 9982x - 40255, \qquad y = 21869x - 3000000 \text{ and } y = 42831x - 10000000$$

The values of R^2 are 0.650, 0.995, and 0.998, which implies the goodness of fit. Here we observe that between the time interval of 12 weeks to 50 weeks (02/05/2020 to 08/01/2021) the slope of the trend line is more than two times the slope before 12 weeks (That is, before 02/05/2020) and after 50 weeks (That is, after 08/01/2021) it almost doubled, which implies the number of infected cases increasing severely with time in Brazil. In France, the curve describing the number of infections needs six-line segments to capture it well (see Figure 5). The straight lines are $y = 7545x - 441,\ y = 25564x - 3000000, y = 64032x - 2000000,\ y = 16856x - 6000000,\ y = 28948x + 4000000$ and $y = 10951x - 3000000$ respectively. From these equations, we notice that there exist some ups and downs in the slopes of the straight lines. Between 30 to 41 weeks (26/08/2020 to 11/11/2020) the gradient of the trend lines is very high, which indicates that in this time interval the number of infected cases boosted up. In the case of Russia, the infected curve is well fitted by four straight lines as shown in Figure 6, which are given by $y = 2750x - 9452,\ y = 16074x - 5000000, y = 65833x + 46190$ and $y = 44988x - 35118$. The values of the slopes (That is, 2750, 16074, 65833, 44988) indicate the ups and downs in the graph of the number of infections. In Turkey, the equations of the seven trend lines, which are needed to fit the infected graph, (see Figure 7) are $y = 6716x - 19243,\ y = 29602x - 10000000,\ y = 24512x + 23905, y = 67939x - 1000000, y = 48902x + 2000000, y = 69766x - 48518$ and $y = 16728x - 6000000$. . Here also a variation in the

values of the slope of the trend lines are noticed, which shows that the increment of infected cases also varies in different time slots. The values of R^2 are 0.513, 0.972, 0.974, 0.961, 0.983, 0.989, and 0.971.

4. Research Outcomes

In Table 1 we consider top 25 productive countries based on TP in COVID-19 related research. Ranking is given based on the TP.

Table 1. Leading countries in COVID-19 research development.

				Citation Threshold				
Rank	Country	TP	H-index	≥1000	≥500	≥200	≥100	≥50
1	United States	38939	272	34	108	402	914	1930
2	United Kingdom	15117	186	23	54	169	385	815
3	China	14654	279	57	145	384	724	1210
4	Italy	11476	153	6	28	111	288	674
5	India	10726	95	3	9	31	88	249
6	Canada	6516	122	7	21	66	156	324
7	Spain	6421	105	4	15	45	111	270
8	Germany	5965	132	10	28	87	178	358
9	Australia	5881	115	7	18	48	140	285
10	France	4811	118	6	23	68	142	306
11	Brazil	4699	76	3	10	23	59	132
12	Turkey	3883	62	1	4	10	34	89
13	Iran	3790	75	0	5	14	50	134
14	Saudi Arabia	3279	64	1	5	19	36	88
15	Japan	2903	75	5	13	26	58	103
16	Netherlands	2880	102	5	19	54	106	201
17	Switzerland	2669	97	4	11	41	92	193
18	South Korea	2527	76	1	6	24	61	109
19	Pakistan	2097	53	0	2	8	21	58
20	South Africa	2085	55	1	4	7	29	64
21	Poland	2063	55	1	3	7	20	63
22	Indonesia	1924	40	1	1	6	12	24
23	Egypt	1907	51	0	3	10	22	54
24	Belgium	1848	78	2	6	23	55	127
25	Sweden	1797	71	2	10	19	42	102

Table 1 includes 25 countries in terms of the TP on the current burning topic COVID-19. The Table 1 will help to overview the research scenario at a glance. Among twenty-five countries, eleven belong to Europe (UK, Italy, Spain, Germany, France, Turkey, Netherlands, Switzerland, Poland, Belgium, and Sweden); two in North America (the USA, and Canada); Brazil in South America; eight in Asia (China, India, Pakistan, Iran, Saudi Arabia, Japan, Indonesia, and South Korea); Australia in Oceania, and two are in Africa (South Africa, and Egypt). The USA comfortably is in the leading position having published 38939 research papers/articles within a short time. The U.K. occupies the second position in terms of TP with 15117 publications. But there is a significant difference/gap between the USA and the UK in terms of TP. In terms of the H-index, China secures 1st position having a value of 279 whereas the USA bears 272 H-index values. UK has consistency in terms of TP and H-index values. If we look at the citation threshold value, we notice that China retains a better position than the USA. Fifty-seven (57) papers have crossed the milestone of 1000 citations whereas in the USA only 34 papers have reached the milestone. There are ten countries in Table 1 which have at least five papers having more than 1000 citations.

Iran, Pakistan, and, Egypt has no papers over the threshold of 1000 citations but these countries respectively have five, two, and three papers over the threshold of 500 citations. According to the 200, 100, and 50 citation thresholds, the USA is in the leading position within the Table 1. Though Indonesia is at the twenty-second position in the Table 1 of the top 25 countries in respect of TP, it has the least H-index (40). All other countries in Table 1 except Indonesia have an h-index value of more than fifty. Figure 8 presents the top ten countries according to the h-index.

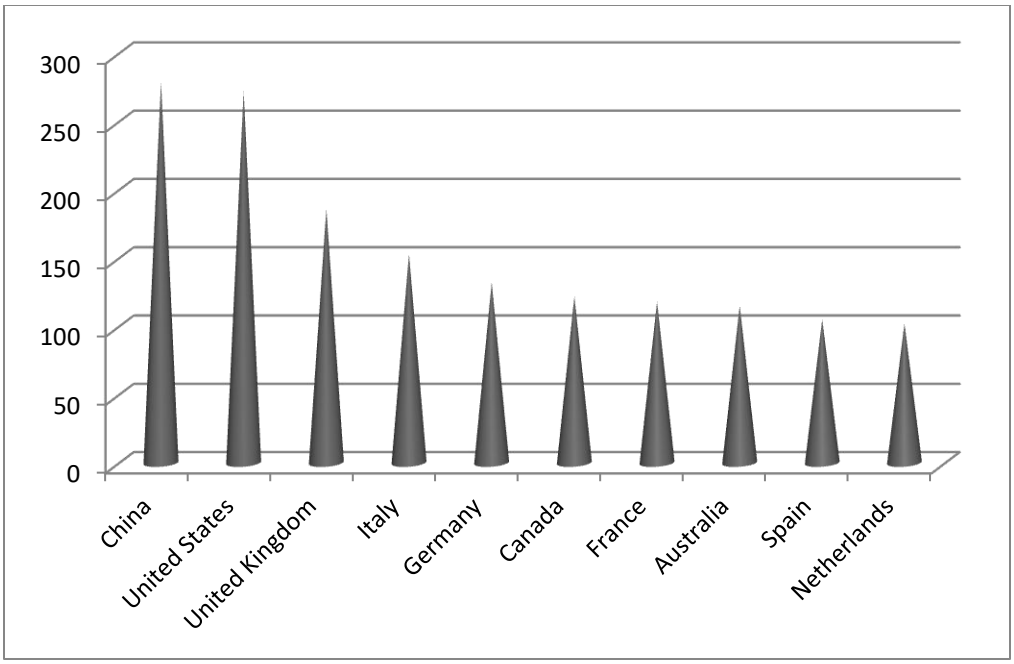

Figure 8. Top ten countries according to h-index

Figure 9 presents the top ten countries according to number of papers more than the threshold of 100 citations.

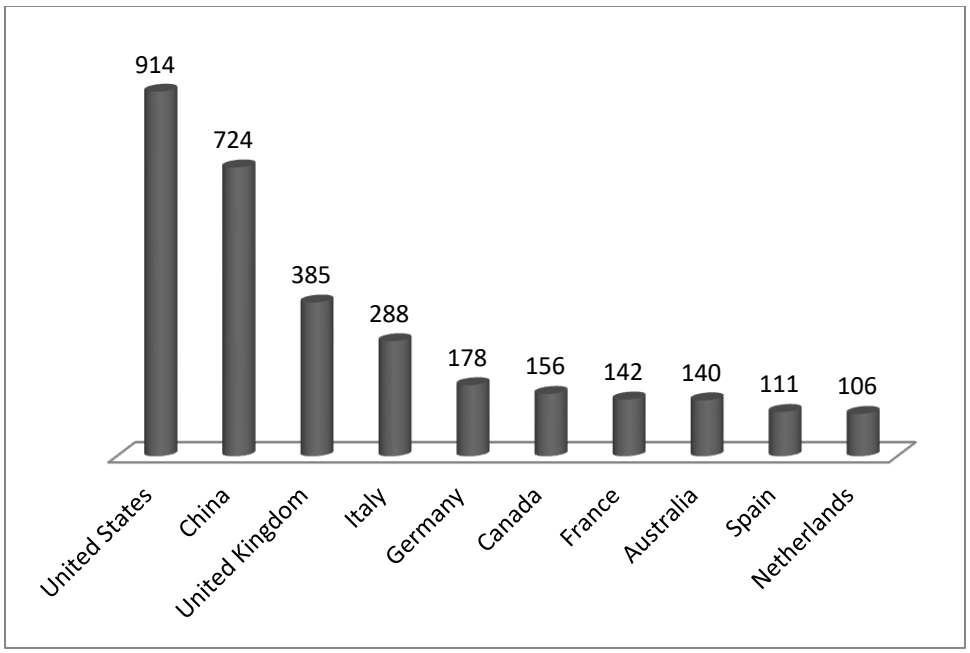

Figure 9. Top ten countries according to number of papers more than 100 citations

Almost all countries around the world are strongly involved in Covid-19 related research. In order to identify the leading ones, let us look into the results according to some well-known bibliometric indicators. Table 1 presents the 25 most productive countries in this field. In Table 2 we prepared a ranking of the top 20 countries by their research performance. Research Score (R_s) is calculated based on the indicators TP, H-index, and threshold of 50 citations (T50-index) using formula

$$R_s = \frac{\log(TP_i + 1)}{max\log(TP + 1)} + \frac{\log(H_i + 1)}{max\log(H + 1)} + \frac{\log(T50_i + 1)}{max\log(T50 + 1)}$$

Table 2. Top 20 countries based their performance in covid-19 related research

Rank	Name of the Country	Research Score (R_s)
1	United States	2.995507
2	China	2.845873
3	United Kingdom	2.724994
4	Italy	2.639395
5	Germany	2.468024
6	Canada	2.449359
7	India	2.417847
8	Australia	2.412365
9	France	2.407266
10	Spain	2.397555
11	Netherlands	2.277783
12	Switzerland	2.256415
13	Brazil	2.217219
14	Iran	2.196537
15	Japan	2.136838
16	South Korea	2.133453
17	Belgium	2.128442
18	Turkey	2.111945
19	Saudi Arabia	2.100024
20	Sweden	2.080609

Now look at the spearman's rho correlation coefficient to examine correlation among the different rankings based on publications, H-index, T50 index, and our combined index. We considered ranking of top 10 countries of Table 2 under different the bibliometric measures to determine the spearman's rho correlation coefficient and results are presented in Table 3.

Table 3. The spearman's rho correlation coefficient under different the bibliometric measures

Indexes	Combined	Combined	Combined	TP	TP	T50

	& TP	& H	& T50	& H	& T50	& H
spearman's rho correlation coefficient	$\frac{139}{165}$ = 0.842	$\frac{149}{165}$ = 0.903	$\frac{151}{165}$ = 0.915	$\frac{37}{55}$ = 0.673	$\frac{23}{33}$ = 0.697	$\frac{163}{165}$ =0.988

From Table 3, one may note that our combined index is positively correlated with all the three indexes TP, H index, and T50. Ranking of the universities under the total publication and H-index are negatively correlated while total citation and H-index are almost perfectly correlated. Upcoming Subsections (4.1 to 4.11) discuss the contribution of each of the leading countries separately in terms of leading topics, subject areas, authors, and institutions. Moreover, it explores leading articles of these countries and reviews the impact of those articles.

4.1 USA

Subsection 4.1 presents contribution of USA in COVID-19 related research. Table 4 shed light on the top twenty-five authors, subject area, and institution of the USA in terms of TP.

Table 4. Leading authors, institutions, subject areas, and keywords in COVID-19 research in USA

R	Authors	TP	Subject area	TP	Institution	TP
1	Lippi, G.	63	Medicine	24635	Harvard Medical School	2140
2	Krammer, F.	58	Social Sciences	5986	Massachusetts General Hospital	1061
3	Baric, R.S.	52	Biochemistry, Genetics and Molecular Biology	4264	Icahn School of Medicine at Mount Sinai	953
4	Henry, B.M.	48	Immunology and Microbiology	2843	Brigham and Women's Hospital	916
5	Alter, G.	38	Psychology	2345	University of Washington	908
6	Amanat, F.	38	Nursing	2286	University of California, San Francisco	885
7	Greninger, A.L.	37	Environmental Science	1881	University of Pennsylvania	844
8	Al-Tawfiq, J.A.	36	Multidisciplinary	1608	University of Michigan, Ann Arbor	742
9	Diamond, M.S.	33	Pharmacology, Toxicology and Pharmaceutics	1388	Stanford University	716
10	Gholamrezanezhad, A.	33	Health Professions	1308	Johns Hopkins University	660
11	Jerome, K.R.	33	Business, Management and Accounting	1279	Yale School of Medicine	650
12	Shi, P.Y.	33	Neuroscience	1261	University of California, Los Angeles	647
13	Brodie, D.	31	Computer Science	1238	Columbia University	627
14	Memish, Z.A.	31	Engineering	1159	Weill Cornell Medicine	622

15	Menachery, V.D.	31	Agricultural and Biological Sciences	1012	Mayo Clinic	613
16	Chowell, G.	30	Economics, Econometrics and Finance	993	University of California, San Diego	610
17	García-Sastre, A.	30	Arts and Humanities	985	The University of North Carolina at Chapel Hill	606
18	Hall, A.J.	30	Chemistry	887	Stanford University School of Medicine	606
19	Latkin, C.A.	30	Mathematics	585	Johns Hopkins School of Medicine	604
20	McCullough, P.A.	29	Physics and Astronomy	566	National Institutes of Health NIH	602
21	Sette, A.	29	Chemical Engineering	457	Harvard T.H. Chan School of Public Health	601
22	Casadevall, A.	28	Materials Science	423	Johns Hopkins Bloomberg School of Public Health	598
23	Pinsky, B.A.	28	Decision Sciences	282	University of Pennsylvania Perelman School of Medicine	582
24	Barouch, D.H.	27	Energy	263	Yale University	546
25	Lipsitch, M.	27	Earth and Planetary Sciences	257	University of Toronto	539

Professor Lippi, G possesses the highest position in the list of leading authors with 63 publications. Professor F. Krammer and Professor R.S. Baric respectively are the second and third-ranked authors for the USA in COVID-19 research. It is also seen that most of the published papers belong to the field /area of medicine which is very obvious because researchers are actively engaged in the discovery of effective medicine or vaccine to save from the grip of the fatal virus. The USA is the worst affected country in the world and so the USA reinforced to prepare the vaccine or medicine for immediate remedy. Thus, the subject area of medicine has gained utmost priority and immediate urgency. Subject areas 'Social Sciences' and 'Biochemistry, Genetics and Molecular Biology' are respectively the second and third leading research areas in the USA for COVID-19 research. Harvard Medical School has the highest number of publications with a total of 2140 publications followed by Massachusetts General Hospital, which has 1061 publications in COVID-19 research. Table 5 presents information for the top ten most-cited COVID-19-related articles written by authors from the USA.

Table 5. List of leading articles of USA

R	Title	Authors	Journal	Citation
1	Presenting Characteristics, Comorbidities, and Outcomes among 5700 Patients Hospitalized with COVID-19 in the New York City Area	Richardson S., Hirsch J.S., Narasimhan M., et al. (2020)	JAMA - Journal of the American Medical Association	3476
2	First case of 2019 novel coronavirus in the	Holshue M.L., DeBolt C.,	New England Journal	2863

	United States	Lindquist S., et al. (2020)	of Medicine	
3	A trial of lopinavir-ritonavir in adults hospitalized with severe COVID-19	Cao B., Wang Y., Wen D., Liu W., et al. (2020)	New England Journal of Medicine	2668
4	Neurologic Manifestations of Hospitalized Patients with Coronavirus Disease 2019 in Wuhan, China	Mao L., Jin H., Wang M., et al., (2020)	JAMA Neurology	2655
5	The incubation period of coronavirus disease 2019 (COVID-19) from publicly reported confirmed cases: Estimation and application	Lauer S.A., Grantz K.H., Bi Q., et al., (2020)	Annals of Internal Medicine	2208
6	Remdesivir for the treatment of COVID-19 — Final report	Beigel J.H., Tomashek K.M., Dodd L.E., et al., (2020)	New England Journal of Medicine	2186
7	Safety and efficacy of the BNT162b2 mRNA COVID-19 vaccine	Polack F.P., Thomas S.J., Kitchin N., et al., (2020)	New England Journal of Medicine	2180
8	Receptor recognition by the novel coronavirus from Wuhan: An analysis based on decade-long structural studies of SARS coronavirus	Wan Y., Shang J., Graham R., Baric R.S., Li F. (2020)	Journal of Virology	1953
9	The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak	Rothan H.A., Byrareddy S.N. (2020)	Journal of Autoimmunity	1910
10	Pulmonary vascular endothelialitis, thrombosis, and angiogenesis in COVID-19	Ackermann M., Verleden S.E., Kuehnel M., et al., (2020)	New England Journal of Medicine	1810

Richardson et al. (2020) examined the characteristics, comorbidities, and, outcomes of the 5700 patients admitted to hospitals in New York City with the symptom of COVID-19. The number of citations (3476) ensures the quality of the paper. Holshue et al. (2020) discussed the first case of coronavirus in the USA. The paper has been published in the well-reputed New England Journal of Medicine. A clinical trial of different drugs started in war-time activities. A trial of lopinavir-ritonavir in adults hospitalized with severe COVID-19 has been noted by Cao et al. (2020). It is supposed that the drugs lopinavir and ritonavir may be effective to fight against the deadly virus. This paper is also included in the list of leading articles in the U.K. and, China. The paper has also a good number of citations. The effect of the fatal coronavirus was so horrible that the whole world was keenly waiting for the preventive vaccine. So, the paper reinforcing the clinical trials of lopinavir-ritonavir has received major attention from researchers. Beigel et al. (2020) also submitted a report about the use of the much-discussed drug Remdesivir. Mao et al. (2020) pointed out the neurologic manifestations. They think that different aspects of neurologic manifestations are yet to be explored. They studied patients admitted for one month (16th January 2020 to 19th February 2020) to the Huazhong University of Science and Technology in Wuhan of China to reach their conclusion. Mao et al. (2020) also belongs to the list of authors in China. Ackermann et al. (2020) compared two types of lungs of seven expired patients – one

from COVID-19 virus and the other from acute respiratory distress syndrome and observed that there exist severe endothelial injury and angiocentric inflammation in the lungs of dead patients from the COVID-19 virus. Wan et al. (2020) studied the structure of coronavirus (2019n-CoV) that emerged from the Wuhan province of China based on the prior knowledge of SARS-CoV-2. They concluded that 2019n-CoV-2 uses Angiotensin-Converting Enzyme-2 (ACE2) as its host receptor and may be severe to humans due to its mutant nature. Rothan et al. (2020) focused on the symptoms of patients, way of transmission, and pathogens and emphasizes finding out the way to prevention of the virus. Out of the ten leading papers five (05) have been published in the famous journal New England Journal of Medicine. So, we can state that researchers frequently choose this journal for the publication of their papers.

4.2. **United Kingdom**

Subsection 4.2 presents contribution of United Kingdom (UK) in COVID-19 related research. Table 6 presents the top fifteen authors, subject area, and institution of the UK in terms of TP.

Table 6. Leading authors, subject areas, and institutions in COVID-19 research in UK

R	Authors	TP	Subject area	TP	Institution	TP
1	Smith, L.	57	Medicine	9237	University of Oxford	1414
2	Zumla, A.	54	Social Sciences	2401	University College London	1267
3	Eggo, R.M.	52	Biochemistry, Genetics and Molecular Biology	1561	Imperial College London	1149
4	Griffiths, M.D.	51	Immunology and Microbiology	957	King's College London	943
5	Khunti, K.	51	Psychology	862	University of Cambridge	725
6	Zambon, M.	46	Environmental Science	820	London School of Hygiene & Tropical Medicine	685
7	Funk, S.	45	Nursing	762	The University of Manchester	583
8	Hopkins, C.	45	Business, Management and Accounting	738	University of Oxford Medical Sciences Division	575
9	Jit, M.	45	Multidisciplinary	529	The University of Edinburgh	567
10	Abbott, S.	41	Engineering	511	University of Liverpool	526
11	Harky, A.	41	Arts and Humanities	503	University of Birmingham	461
12	Klenerman, P.	40	Computer Science	487	University of Bristol	354
13	Jarvis, C.I.	39	Neuroscience	482	University of Glasgow	348
14	Edmunds, W.J.	38	Economics, Econometrics and Finance	474	Nuffield Department of Medicine	347
15	Kucharski, A.J.	37	Pharmacology, Toxicology and Pharmaceutics	452	Public Health England	346

Professor L. Smith has 57 publications securing the top position in Table 6 followed by Professor A. Zumla and Professor R.M. Eggo. The top five authors have more than fifty publications in COVID-19 related research. The world-famous institute the University of Oxford occupies first place with 1414 publications. The University College London and Imperial College London respectively have 1267 and 1149 publications in COVID-19 research and are in the second and third position in the list of the leading institution in the UK. An interesting observation is that the Table 6 contains mostly the university name which ensures the excellent performance of the universities in the UK in advancing the research on COVID-19. It is earlier mentioned that the subject 'medicine' is the highest priority, and focuses on this emergent situation. So, the medicinal sector has the most publication bearing the number 9237. Note that, leading subject areas in COVID-19 research are quite similar to the USA. Table 7 presents information for the top ten most-cited COVID-19 related articles written by authors from the UK.

Table 7. List of leading articles in U.K.

R	Title	Authors	Journal	Citation
1	Virological assessment of hospitalized patients with COVID-2019	Wölfel R., Corman V.M., Guggemos W., et al. (2020)	Nature	2685
2	A trial of lopinavir-ritonavir in adults hospitalized with severe COVID-19	Cao B., Wang Y., Wen D., et al. (2020)	New England Journal of Medicine	2668
3	Dexamethasone in hospitalized patients with COVID-19	Horby P., Lim W.S., Emberson J.R., et al. (2020)	New England Journal of Medicine	2359
4	Remdesivir for the treatment of COVID-19 — Final report	Beigel J.H., Tomashek K.M., Dodd L.E., et al. (2020)	New England Journal of Medicine	2186
5	Safety and efficacy of the BNT162b2 mRNA COVID-19 vaccine	Polack F.P., Thomas S.J., Kitchin N., et al. (2020)	New England Journal of Medicine	2180
6	World Health Organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19)	Sohrabi C., Alsafi Z., O'Neill N., et al. (2020)	International Journal of Surgery	1735
7	Multidisciplinary research priorities for the COVID-19 pandemic: a call for action for mental health science	Holmes E.A., O'Connor R.C., Perry V.H., et al. (2020)	The Lancet Psychiatry	1617
8	The socio-economic implications of the coronavirus pandemic (COVID-19): A review	Nicola M., Alsafi Z., Sohrabi C., et al. (2020)	International Journal of Surgery	1506
9	Remdesivir in adults with severe COVID-19: a randomized, double-blind, placebo-controlled, multicenter trial	Wang Y., Zhang D., Du G., et al. (2020)	The Lancet	1455
10	The trinity of COVID-19: immunity, inflammation and intervention	Tay M.Z., Poh C.M., Rénia L., MacAry P.A.,	Nature Reviews Immunology	1388

		Ng L.F.P. (2020)		

The virological assessment of hospitalized patients with COVID-2019 was reviewed by Wolfe et al., (2020) of the UK. The study was published in Nature and received 2685 citations in a short time. It shows that the study has received a lot of attention from the researchers. The effect of remdesivir was reported by Beigel et al., (2020). To examine the effect, they purposely applied a 10 days course of remdesivir and placebo to the 1062 patients and observed the result. They saw that patients treated with remdesivir quickly recovered than the patients treated without remdesivir. It also reduces tracheal infection of the COVID-19 confirmed patients. Holmes et al. (2020) have shown their interest to evaluate the diverse effects of the pandemic on society including social and mental health. They stress the collaborative and inter-disciplinary research and collection of data across the globe to find the fruitful result of the research. Nicola et al., (2020) also presented a review paper depicting the global socio-economic scenario due to the sudden advent of the calamitous virus. They tried to explore the changes pre- and post-pandemic situations in different sectors like education, production of commodities, the field of medicine, the food sector, etc. Sohrabi et al., (2020) made a review of the 2019 novel coronavirus and inferred that rigorous surveillance, minute observation, and hard work are urgently needed to comprehend the nature of the devastating virus. Tay et al., (2020) analysed the different mechanisms of SARS-CoV2, and emphasize immunopathogenesis. They inferred that T-cell may take an effective role to prevent the infection of the virus. They also emphasized more research in this direction. Wang, Y. et al., (2020) studied the viral infected adult patients admitted to the ten hospitals in the Hubei province of China. The patients were treated with a controlled dose of remdesivir drug but after due observation, no significant result has been obtained of the many discussed remdesivir drug.

4.3. China

Subsection 4.3 presents contribution of China in COVID-19 related research. Table 8 presents the top fifteen authors, subject area, and institution of China in terms of TP.

Table 8. Leading authors, subject areas, and institutions in COVID-19 research in China

R	Authors	TP	Subject area	TP	Institution	TP
1	Lu, H.	57	Medicine	8224	Huazhong University of Science and Technology	1484
2	To, K.K.W.	46	Biochemistry, Genetics and Molecular Biology	2280	Tongji Medical College	1324
3	Yuen, K.Y.	46	Immunology and Microbiology	1563	Chinese Academy of Sciences	891
4	Chan, J.F.W.	44	Environmental Science	1279	Ministry of Education China	794
5	Zhao, S.	42	Social Sciences	1233	Fudan University	583
6	Liu, L.	41	Engineering	935	Chinese Academy of Medical Sciences & Peking Union Medical College	566
7	Hu, Y.	40	Pharmacology, Toxicology and Pharmaceutics	927	Wuhan University	525
8	Zhang, Z.	38	Computer Science	831	University of Chinese Academy of Sciences	498
9	Ling, Y.	37	Psychology	638	Renmin Hospital of Wuhan University	460
10	Zhong, N.	37	Multidisciplinary	535	Zhejiang University	442
11	Gao, G.F.	36	Chemistry	521	Capital Medical University	440
12	He, D.	36	Mathematics	485	Sun Yat-Sen University	432
13	Bilal, M.	35	Economics, Econometrics and Finance	444	Peking University	402
14	Cheung, T.	32	Nursing	432	Tsinghua University	397
15	Hung, I.F.N.	31	Business, Management and Accounting	423	Zhongnan Hospital of Wuhan University	393

Professor H. Lu leads the list of leading authors in Table 8 followed by K.K.W. To and K. Y. Yuen. H. Lu has authored 57 research articles based on COVID-19 related issues. Expectedly, Chinese research works are evolved the majority in the area of medicine. Differing from the USA and UK, besides medicine, Chinese research works emphasized on research areas 'Biochemistry, Genetics and Molecular Biology and 'Immunology and Microbiology'. Huazhong University of Science and Technology, and Tongji Medical College are the leading institution in China for COVID-19 related research works. Seven institutions have more than five hundred publications. Table 9 presents the list of leading influential articles from China on COVID-19 related research works.

Table 9. **List of leading articles of China**

R	Title	Authors	Journal	Citation
1	Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China	Huang C., Wang Y., Li X., Ren L., et al. (2020)	The Lancet	18794
2	Clinical characteristics of coronavirus disease 2019 in China	Guan W., Ni Z., Hu Y., et al. (2020)	New England Journal of Medicine	12264

3	Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study	Zhou F., Yu T., Du R., Fan G., et al. (2020)	The Lancet	10827
4	A novel coronavirus from patients with pneumonia in China, 2019	Zhu N., Zhang D., Wang W., et al. (2020)	New England Journal of Medicine	10317
5	Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study	Chen N., Zhou M., Dong X., et al. (2020)	The Lancet	8870
6	A pneumonia outbreak associated with a new coronavirus of probable bat origin	Zhou P., Yang X.-L., Wang X.-G., et al. (2020)	Nature	7987
7	Genomic characterization and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding	Lu R., Zhao X., Li J., et al. (2020)	The Lancet	4905
8	A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster	Chan J.F.-W., Yuan S., Kok K.-H., et al. (2020)	The Lancet	4074
9	Pathological findings of COVID-19 associated with acute respiratory distress syndrome	Xu Z., Shi L., Wang Y., Zhang J., et al. (2020)	The Lancet Respiratory Medicine	3935
10	A new coronavirus associated with human respiratory disease in China	Wu F., Zhao S., Yu B., et al. (2020)	Nature	3819
11	Risk Factors Associated with Acute Respiratory Distress Syndrome and Death in Patients with Coronavirus Disease 2019 Pneumonia in Wuhan, China	Wu C., Chen X., Cai Y., et al. (2020)	JAMA Internal Medicine	3426
12	Immediate psychological responses and associated factors during the initial stage of the 2019 coronavirus disease (COVID-19) epidemic among the general population in China	Wang C., Pan R., Wan X., Tan Y., Xu L., Ho C.S., Ho R.C.	International Journal of Environmental Research and Public Health	2987
13	A trial of lopinavir-ritonavir in adults hospitalized with severe COVID-19	Cao B., Wang Y., Wen D., et al. (2020)	New England Journal of Medicine	2668
14	Neurologic Manifestations of Hospitalized Patients with Coronavirus Disease 2019 in Wuhan, China	Mao L., Jin H., Wang M., et al. (2020)	JAMA Neurology	2655
15	Correlation of Chest CT and RT-PCR Testing for Coronavirus Disease 2019 (COVID-19) in China: A Report of 1014 Cases	Ai T., Yang Z., Hou H., et al. (2020)	Radiology	2335
16	Factors associated with mental health outcomes among health care workers exposed to coronavirus disease 2019	Lai J., Ma S., Wang Y., et al. (2020)	JAMA Network Open	2174
17	Dysregulation of immune response in patients with coronavirus 2019 (COVID-19) in Wuhan, China	Qin C., Zhou L., Hu Z., et al. (2020)	Clinical Infectious Diseases	1859
18	Structural basis for the recognition of SARS-CoV-2 by full-length human ACE2	Yan R., Zhang Y., Li Y., et al. (2020)	Science	1824
19	Clinical and immunological features of severe and moderate coronavirus disease 2019	Chen G., Wu D., Guo W., et al. (2020)	Journal of Clinical Investigation	1812
20	The origin, transmission and clinical therapies on coronavirus disease 2019 (COVID-19) outbreak- A n update on the status	Guo Y.R., Cao Q. D., Hong Z.S., et al. (2020)	Military Medical Research	1762

Huang et al. (2020) made a case study taking into account forty (41) patients admitted in a hospital in Wuhan city of China being infected by a 2019 novel coronavirus. The median age of the patients was 49 and they observed that pneumonia was common of all patients with different levels of chest injury and some of them have to be treated in ICU. But surprisingly it is seen that ICU patients are in a better position than non-ICU patients in terms of plasma level. The paper was published in the world-famous medical journal 'The Lancet' bearing a magnificent number of citations with 18794 ensuring its quality. To characterize the deadly virus, Guan et al. (2020) gathered data of 1099 patients from 552 hospitals with different demography of China. The paper got a remarkable number of citations with a total of 12264 within a very short time. After the investigations of 191 patients admitted to two hospitals in China (Jinyintan Hospital, and Wuhan Pulmonary Hospital), Zhou, F. et al. (2020) summarised that patient with more than 1μg/ml d-dimer have a very high risk. The paper was published in the highly reputed medical journal 'The Lancet' and received over 10000 citations. Zhu et al. (2020) has given importance to the mode of transmission, an interval of reproduction, clinical spectrum, and above all stress on the determination of strategy how to check the spread of the virus. They also pointed out the continuous and minute observation of the characters of the virus. Investigation about the clinical and epidemiological characteristics of 99 patients from Wuhan Jinyintan Hospital has been done by Chen, N. et al. (2020), and they come to the conclusion that the virus has become very severe to the aged males having comorbidities. They also suggest more and deep investigation/study for the prediction of the risk of mortality. Zhou, P. et al. (2020) provided a detailed study of the 2019 novel SARS CoV-2 pointing out the possible responsible agent for current catastrophe in human life. They also notice the existence of nucleotide positive and viral-protein seroconversion of all patients with confirmed cases. They focus on more exploration in this regard. Lu et al. (2020) interpreted that the 2019 novel coronavirus has a strong affinity with the human receptor ACE-2. They also guessed that while bats may have been the original host, some animals may have acted as a catalyst to spread the virus to humans. After a careful examination of a household with six patients, Chan et al. (2020a) stressed the need of avoiding human-to-human transmission of the virus. Xu et al. (2020) hope that their research will help to explore pathogens, and will be able to assist in mitigating the mortality rate. After studying a patient admitted to the Central Hospital of Wuhan being infected by the virus who worked at the local seafood market in Wuhan city, Wu, C. et al. (2020) emphasized the importance of doing extensive research to explore the natural and

intermediate hosts. Note that, the article developed by Cao et al (2020) [Sl No-13 in Table 9] has been described in both the USA, and the U.K., and the article presented by Mao et al. (2020) [Sl No. 14 in Table 9] has been discussed earlier in the section of U.K. The Table 9 reveals that the leading articles of China have received a significant number of citations; four out of ten papers have got more than 10000 citations. Chinese articles get more citations as initial pieces of evidence about the impact of the 2019 novel coronavirus received from China. Researchers all over the world followed research outcomes and patient observation from various Chinese hospitals.

4.4. Italy

Subsection 4.4 presents contribution of another badly COVID-19 affected country, Italy in COVID-19 related research. Table 10 presents the top fifteen authors, subject area, and institution of Italy based on the TP.

Table 10. Leading authors, subject areas, and institutions in COVID-19 research in Italy

R	Authors	TP	Subject area	TP	Institution	TP
1	Lippi, G.	87	Medicine	7951	Università degli Studi di Milano	1140
2	Landoni, G.	61	Biochemistry, Genetics and Molecular Biology	1757	Sapienza Università di Roma	1129
3	Ciceri, F.	55	Immunology and Microbiology	957	Università degli Studi di Padova	719
4	Buonsenso, D.	53	Social Sciences	899	Università degli Studi di Napoli Federico II	594
5	Nicastri, E.	49	Environmental Science	809	Fondazione Policlinico Universitario Agostino Gemelli IRCCS	525
6	Henry, B.M.	47	Psychology	533	Alma Mater Studiorum Università di Bologna	492
7	Ippolito, G.	47	Pharmacology, Toxicology and Pharmaceutics	517	Università degli Studi di Torino	464
8	Zangrillo, A.	47	Neuroscience	470	Università Cattolica del Sacro Cuore, Campus di Roma	434
9	Mussini, C.	46	Computer Science	390	Consiglio Nazionale delle Ricerche	418
10	Bassetti, M.	45	Nursing	349	Università degli Studi di Pavia	399
11	Bruno, R.	45	Engineering	337	Ospedale Maggiore Policlinico Milano	393
12	Mastroianni, C.M.	42	Multidisciplinary	321	Università degli Studi di Genova	391
13	Cecconi, M.	41	Agricultural and Biological Sciences	293	Università degli Studi della Campania Luigi Vanvitelli	387
14	Girardis, M.	41	Chemistry	261	Università degli Studi di Milano-Bicocca	383
15	Franceschi, F.	40	Health Professions	260	Università degli Studi di Roma Tor Vergata	382

Professor Giuseppe Lippi from the University of Verona has the most (87) number of publications. Note that, Professor Lippi also leads in the USA. This is an incredible performance as he leads in two countries (USA and Italy) through collaborative works. Professor G. Landoni and F. Ciceri are in the second and third positions with 61 and 55 publications respectively. The top fifteen authors of Italy have more than or equal to forty publications. Among the 11476 publications, 7951 are in the area of medicine. 'Biochemistry, Genetics and Molecular Biology' and 'Immunology and Microbiology' are the other two leading research areas in Italy. There are more than eight hundred publications in the areas 'Social Sciences' and 'Environmental Science'. Interestingly, there are 533 publications on Psychology. This evidence shows that fear of COVID-19 and its obligations has a huge impact on public psychological health. Università degli Studi di Milano and Sapienza Università di Roma are two the leading institutions with 1140 and 1129 publications on COVID-19 related research. Five universities of Italy have more than five hundred publications.

4.5. India

Table 11 presents the top fifteen authors, subject area, and institution of Italy based on the TP.

Table 11. Leading authors, subject areas, and institutions in COVID-19 research in India

R	Authors	TP	Subject area	TP	Institution	TP
1	Dhama, K.	109	Medicine	5314	All India Institute of Medical Sciences, New Delhi	526
2	Tiwari, R.	56	Biochemistry, Genetics and Molecular Biology	1749	Postgraduate Institute of Medical Education & Research, Chandigarh	377
3	Bhatnagar, S.	40	Social Sciences	1228	Datta Meghe Institute of Medical Sciences Deemed to be University	215
4	Misra, S.	39	Pharmacology, Toxicology and Pharmaceutics	1156	Manipal Academy of Higher Education	208
5	Vaishya, R.	37	Computer Science	792	University of Delhi	200
6	Misra, A.	36	Environmental Science	764	Saveetha Institute of Medical and Technical Sciences	175
7	Malik, Y.S.	34	Immunology and Microbiology	743	Indian Council of Medical Research	170
8	Sharun, K.	33	Engineering	638	Saveetha Dental College And Hospitals	157
9	Medhi, B.	32	Agricultural and	484	Amity University	153

			Biological Sciences			
10	Rodriguez-Morales, A.J.	31	Business, Management and Accounting	431	Sanjay Gandhi Postgraduate Institute of Medical Sciences Lucknow	144
11	Sah, R.	31	Economics, Econometrics and Finance	401	Indian Council of Agricultural Research	137
12	Javaid, M.	29	Mathematics	397	All India Institute of Medical Sciences, Jodhpur	133
13	Rabaan, A.A.	29	Chemistry	383	Banaras Hindu University	124
14	Sharma, P.	29	Chemical Engineering	247	Indian Veterinary Research Institute	122
15	Suri, V.	28	Neuroscience	247	Jamia Millia Islamia	122

Professor K Dhama, principal scientist of the Indian Veterinary Research Institute, Izatnagar has authored a total of 107 papers. He is the most productive author for India as well as the World in COVID-19 related research. Professor R. Tiwari is in the second position on the list of leading Indian authors with 56 publications. Among the 10726 articles of India 5314 articles are published in medicine-based journals and 1749 in the area 'Biochemistry, Genetics and Molecular Biology'. More than twelve per cent of articles were published in 'Social Sciences' journals. Indian researchers also focused on 'Pharmacology, Toxicology and Pharmaceutics' journals and published 1156 articles in this area. All India Institute of Medical Sciences, New Delhi is the leading institution in India with 526 publications. Five institutions of India in Table 11 have more than 200 publications.

4.6. Canada

Table 12 presents the top fifteen authors, subject area, and institution of Canada based on the TP.

Table 12. Leading authors, subject areas, and institutions in COVID-19 research in Canada

R	Authors	TP	Subject area	TP	Institution	TP
1	Bragazzi, N.L.	56	Medicine	4049	University of Toronto	1527
2	Murthy, S.	35	Social Sciences	1010	The University of British Columbia	814
3	Mubareka, S.	26	Biochemistry, Genetics and Molecular Biology	669	McMaster University	535
4	Dyer, O.	24	Immunology and Microbiology	408	University of Alberta	517
5	Slutsky, A.S.	23	Environmental Science	399	Université McGill	480
6	Halwani, R.	21	Psychology	388	University of Calgary	439
7	Rochwerg, B.	21	Multidisciplinary	259	University of Ottawa	426
8	Abrams, E.M.	20	Neuroscience	258	The University of Western Ontario	314

9	Asmundson, G.J.G.	20	Nursing	257	University of Montreal	296
10	Chattu, V.K.	20	Engineering	230	University of Manitoba	285
11	Finzi, A.	20	Computer Science	220	University Health Network University of Toronto	256
12	Greenshaw, A.J.	19	Agricultural and Biological Sciences	207	Dalhousie University	256
13	Agyapong, V.I.O.	18	Pharmacology, Toxicology and Pharmaceutics	205	York University	246
14	Lamontagne, F.	18	Business, Management and Accounting	202	Saint Michael's Hospital University of Toronto	232
15	Taylor, S.	18	Economics, Econometrics and Finance	182	Hospital for Sick Children University of Toronto	217

Nicola Luigi Bragazzi from York University, Toronto is the leading author in the list of productive authors from Canada (see Table 12). S. Murthy has 35 publications on COVID-19 and gets the second position in Canada. The top eleven authors in Table 12 have more than or equal to twenty publications. Among the 6516 articles of Canada, 4049 articles are published in medicine-based journals and 1010 in the area of 'Social Sciences' journals. More than ten percent of articles were published in 'Biochemistry, Genetics and Molecular Biology' journals. The University of Toronto leads comprehensively with 1527 publications followed by The University of British Columbia in the list of productive institutions from Canada. Seven institutions of Canada in Table 12 have more than 400 publications.

4.7. Spain

Table 13 presents the top fifteen authors, subject area, and institution of Spain based on the TP.

Table 13. Leading authors, subject areas, and institutions in COVID-19 research in Spain

R	Authors	TP	Subject area	TP	Institution	TP
1	Smith, L.	37	Medicine	4061	Universitat de Barcelona	528
2	Torres, A.	30	Social Sciences	786	Hospital Clinic Barcelona	518
3	Jacob, L.	27	Environmental Science	762	Universitat Autònoma de Barcelona	429
4	Soriano, A.	27	Biochemistry, Genetics and Molecular Biology	591	Universidad Complutense de Madrid	429
5	Lechien, J.R.	25	Immunology and Microbiology	417	Hospital General Universitario Gregorio Marañon	370
6	Fernández-Ruiz, M.	24	Psychology	380	Instituto de Salud Carlos III	348
7	Koyanagi, A.	24	Nursing	285	Hospital Universitario La Paz	313
8	Chiesa-Estomba, C.M.	23	Computer Science	261	Hospital Universitari Vall d'Hebron	271
9	Mullol, J.	23	Engineering	236	Hospital Universitario 12 de	267

					Octubre	
10	Estrada, V.	22	Energy	235	Institut d'Investigacions Biomèdiques August Pi i Sunyer - IDIBAPS	256
11	Ferrer, R.	22	Neuroscience	234	Universitat de València	254
12	Horcajada, J.P.	22	Business, Management and Accounting	207	Hospital Universitari de Bellvitge	243
13	Agache, I.	21	Multidisciplinary	196	Hospital Clínico San Carlos de Madrid	236
14	Aguado, J.M.	21	Agricultural and Biological Sciences	189	Universidad Autónoma de Madrid	229
15	García-Azorín, D.	21	Pharmacology, Toxicology and Pharmaceutics	188	Centro de Investigación Biomédica en Red de Enfermedades Respiratorias	218

L. Smith is the leading author in the list of productive authors from Spain (see Table 13) followed by A. Torres. The top five authors in Table 13 have more than or equal to twenty-five publications. The top three leading areas of Spanish authors in COVID-19 research are 'Medicine', 'Social Sciences', and 'Environmental Science'. It is noticeable that more than twelve percent of articles of Spanish authors in COVID-19 research are published in 'Environmental Science' related journals. The University of Barcelona leads among the Spanish institutions with 528 publications followed by Hospital Clinic Barcelona, which has 518 publications in COVID-19 research. Seven institutions of Spain in Table 13 have more than 300 publications.

Table 14. List of leading articles of Italy, India, Canada, Spain

	R	Title	Authors	Journal	Citation
Italy	1	Baseline Characteristics and Outcomes of 1591 Patients Infected with SARS-CoV-2 Admitted to ICUs of the Lombardy Region, Italy	Grasselli G., Zangrillo A., Zanella A., et al. (2020)	JAMA - Journal of the American Medical Association	2230
	2	COVID-19 and Italy: what next?	Remuzzi A., Remuzzi G.	The Lancet	1444
	3	Compassionate use of remdesivir for patients with severe COVID-19	Grein J., Ohmagari N., Shin D., et al. (2020)	New England Journal of Medicine	1344
	4	COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review	Bikdeli B., Madhavan M.V., Jimenez D., et al. (2020)	Journal of the American College of Cardiology	1224
	5	The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak	Chinazzi M., Davis J.T., Ajelli M., et al. (2020)	Science	1164
	6	Olfactory and gustatory dysfunctions as a clinical presentation of mild-to-moderate forms of the coronavirus disease (COVID-19): a multicenter European study	Lechien J.R., Chiesa-Estomba C.M., De Siati D.R., et al. (2020)	European Archives of Oto-Rhino-Laryngology	1068
d u	1	A Review of Coronavirus Disease-2019	Singhal T.	Indian Journal of	1097

		(COVID-19)		Pediatrics	
	2	COVID-19 and mental health: A review of the existing literature	Rajkumar R.P.	Asian Journal of Psychiatry	1042
	3	Clinical, laboratory and imaging features of COVID-19: A systematic review and meta-analysis	Rodriguez-Morales A.J., Cardona-Ospina J.A., Gutiérrez-Ocampo E., et al. (2020)	Travel Medicine and Infectious Disease	1006
Canada	1	Compassionate use of remdesivir for patients with severe COVID-19	Grein J., Ohmagari N., Shin D., et al. (2020)	New England Journal of Medicine	1344
	2	COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review	Bikdeli B., Madhavan M.V., Jimenez D et al. (2020)	Journal of the American College of Cardiology	1224
	3	Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis	Chu D.K., Akl E.A., Duda S., et al. (2020)	The Lancet	1181
	4	Fair allocation of scarce medical resources in the time of COVID-19	Emanuel E.J., Persad G., Upshur R., et al. (2020)	New England Journal of Medicine	1165
	5	Using social and behavioural science to support COVID-19 pandemic response	Bavel J.J.V., Baicker K., Boggio P.S., et al. (2020)	Nature Human Behaviour	1154
	6	Olfactory and gustatory dysfunctions as a clinical presentation of mild-to-moderate forms of the coronavirus disease (COVID-19): a multicenter European study	Lechien J.R., Chiesa-Estomba C.M., De Siati D.R., et al. (2020)	European Archives of Oto-Rhino-Laryngology	1068
	7	A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version)	Jin Y.-H., Cai L., Cheng Z.-S., Cheng H., et al. (2020)	Military Medical Research	1003
Spain	1	Remdesivir for the treatment of COVID-19 — Final report	Beigel J.H., Tomashek K.M., Dodd L.E., et al. (2020)	New England Journal of Medicine	2186
	2	Compassionate use of remdesivir for patients with severe COVID-19	Grein J., Ohmagari N., Shin D., et al. (2020)	New England Journal of Medicine	1344
	3	COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review	Bikdeli B., Madhavan M.V., Jimenez D., et al. (2020)	Journal of the American College of Cardiology	1224
	4	Olfactory and gustatory dysfunctions as a clinical presentation of mild-to-moderate forms of the coronavirus disease (COVID-19): a multicenter European study	Lechien J.R., Chiesa-Estomba C.M., De Siati D.R., et al. (2020)	European Archives of Oto-Rhino-Laryngology	1068

Discussion on the leading articles of Italy, India, Canada, Spain

Italy

The cohort study of Grasselli et al. (2020) over 3988 critical patients in the Lombardy region of Italy reveals the higher mortality rate of the patients. These patients have an urgent need of ICU, and Invasive Mechanical Ventilation (IMV). Remuzzi et al (2020) attempted to depict a picture of healthcare scenarios of Italy after the outbreak of the pandemic. They also reiterated that if the trends of the graph persist, the Italian Government has to take immediate action to increase the health infrastructure to get rescue from such a terrible pandemic situation. Grein et al. (2020) used the remdesivir drug among the 61 hospitalized confirmed infected patients with an oxygen level of less than or equal to 94 oxygen levels and found that this drug may be beneficial to the critically ill. Chinazzi et al. (2020) use a global meta-population disease transmission model. They concluded that inter-national travel restrictions could slow the spread of the novel coronavirus. They also found that early detection, hand washing, self-isolation, and household quarantine are more helpful than travel limitations in preventing the spread of the deadly virus. Lechien et al. (2020) investigated the situation of hospitalized patients with confirmed infection to see the existence of olfactory and gustatory disorder among the patients and observed that these symptoms are frequent/prevalent among European patients. They also stressed the need of identifying the symptom anosmia or ageusia which is regarded as a crucial symptom of COVID-infected patients. Bikdeli et al. (2020) looked at the pathogenesis, epidemiology, and outcomes of the patients and highlighted the need for precaution having a thrombotic disease.

India

Singhal et al. (2020) presented a comprehensive review of COVID-19. In this review paper, the author sheds light on the different features like symptoms of the infected people, and process of treatment, etc. Rajkumar et al. (2020) discussed that COVID-19 has a major adverse effect on the mental health of the common people like anxiety, depression, and mental stress. They also summarized that more research may unfold different aspects in this regard especially for the people belonging at a higher risk due to poor health. After going through the 27 articles Rodriguez-Morales et al. (2020) presented a systematic review and meta-analysis in Indian perspective with three basic objectives – to summarize the results obtained from various laboratory-based clinical examinations, and observations, to review the infrastructure for critical patients, and to estimate the prevalence/frequency of co-morbid patients.

Canada

After going through some research papers related to social and behavioural science Baval et al. (2020) talked about the prevention of threat, social, and behavioural changes, improvement of science communication, leadership, stress, etc. during the pandemic. They also pointed out the research insights of the earlier published papers as well as the gaps. They hope that the paper may help/assist the policymaker to reduce the potentially fatal impacts of COVID-19 by taking immediate intervention in this regard. Chu et al. (2020) presented a systematic review and meta-analysis by collecting a dataset from 21 standard sources recognized by the World Health Organisation (WHO) across 16 countries of six continents. They used the data after careful and proper screening on both health care workers and common people. They observe that close contact with human beings may accelerate the spread of the virus. After a detailed study, they suggest the three main ways for prevention from the spread of SARS-CoV-2 -firstly on keeping greater than a 1-meter distance between each other, second the optimal use of masks namely N-95, surgical and 12–16-layer cotton masks, and the third is the use of goggles, face shields, etc. for protection of eyes. They added that N-95 masks are more effective than surgical masks for health care workers, and the common people may use N-95 masks as well as surgical or cotton masks. Jin et al., (2020) prepared a guideline for the diagnosis and treatment of COVID-19 infected patients based on the available primary data of Zhongan Hospital of Wuhan University. Since the fatal virus is transmitted through droplets, they strongly recommended avoiding unnecessary travel and advised to stay at home. They recommended some measures for frontline line workers like the doctors, nurses, scientists, police, and other people associated with the hospitals, etc. They have suggested various measures for the treatment of the infected people like continuous monitoring with different blood tests, and other clinical examinations. They also suggested oxygen therapy and ECMO support for critical patients. They also pointed out a very controversial matter of whether the drug lopinavir and ritonavir are beneficial or not for corona-infected patients. After deep observation, they summarised that these drugs may be beneficial for the patients if applied at an early stage, but give no fruitful result for late application. They also added that further exploration is needed in this regard. Emanuel et al. (2000) proposed six recommendations for equal distribution, and optimal use of scarce medical resources, as well as a roadmap for equal access to facilities, and opportunity for all. Through their recommendations, they brought attention to a few key points. According to their opinion, equal emphasis should be

equally given to all types of patients (both-COVID, and non-COVID), strong efforts should be made to save the most lives and maximum benefits of individuals, testing, use of PPE should be enhanced, ICU for critical patients should be provided, and special attention is to be given on the researchers as they can do their work freely, and fearlessly for the greater benefit of the society in future. They also stated that patients should be given priority based on scientific evidence rather than on a first-come-first-served basis.

Spain

List of leading articles of Spain are already discussed earlier as these are concurrently listed in another countries namely U.K., Italy, and Canada.

4.8. Germany

Table 15 presents the top fifteen authors, subject area, and institution of Germany based on the TP.

Table 15. Leading authors, subject areas, and institutions in COVID-19 research in Germany

R	Authors	TP	Subject area	TP	Institution	TP
1	Drosten, C.	58	Medicine	3446	Charité – Universitätsmedizin Berlin	525
2	Corman, V.M.	54	Biochemistry, Genetics and Molecular Biology	894	Ludwig-Maximilians-Universität München	364
3	Dittmer, U.	40	Social Sciences	752	Freie Universität Berlin	270
4	Ciesek, S.	33	Immunology and Microbiology	626	Universität Heidelberg	260
5	Netea, M.G.	32	Environmental Science	407	Technical University of Munich	250
6	Lütgehetmann, M.	29	Multidisciplinary	340	Berliner Institut für Gesundheitsforschung	248
7	Kluge, S.	28	Psychology	311	Universitätsklinikum Hamburg-Eppendorf	237
8	Klimek, L.	27	Neuroscience	252	Klinikum der Universität München	233
9	Sander, L.E.	26	Economics, Econometrics and Finance	251	Eberhard Karls Universität Tübingen	187
10	Bousquet, J.	25	Pharmacology, Toxicology and Pharmaceutics	246	Universität Duisburg-Essen	186
11	Kurth, F.	25	Computer Science	241	Universität Freiburg	183
12	Merle, U.	25	Business, Management and Accounting	218	University of Cologne	168
13	Dreher, M.	24	Engineering	192	Harvard Medical School	167
14	Meybohm, P.	23	Agricultural and Biological Sciences	184	Medizinische Hochschule Hannover MHH	167

15	Witzke, O.	23	Chemistry	175	Goethe-Universität Frankfurt am Main	166

German virologist Christian Drosten leads the list of productive authors in Table 15 with 58 publications in COVID-19 research closely followed by another virologist Victor M. Corman from Charité – Universitätsmedizin Berlin, who has 54 publications. The top five authors from Germany in Table 15 have more than thirty publications. The top three leading areas of German authors in COVID-19 research are 'Medicine', 'Biochemistry, Genetics and Molecular Biology', and 'Social Sciences''. Charité – Universitätsmedizin Berlin leads comprehensively among the German institutions with 525 publications followed by Ludwig-Maximilians-Universität München. The top five institutions of Germany in Table 15 have more than or equal to 250 publications.

Table 16. List of leading articles of Germany

R	Title	Authors	Journal	Citation
1	SARS-CoV-2 Cell Entry Depends on ACE2 and TMPRSS2 and Is Blocked by a Clinically Proven Protease Inhibitor	Hoffmann M., Kleine-Weber H., Schroeder S., et al. (2020)	Cell	6634
2	Virological assessment of hospitalized patients with COVID-2019	Wölfel R., Corman V.M., Guggemos W., et al. (2020)	Nature	2685
3	Remdesivir for the treatment of COVID-19 — Final report	Beigel J.H., Tomashek K.M., Dodd L.E., et al. (2020)	New England Journal of Medicine	2186
4	Safety and efficacy of the BNT162b2 mRNA COVID-19 vaccine	Polack F.P., Thomas S.J., Kitchin N., et al. (2020)	New England Journal of Medicine	2180
5	Pulmonary vascular endothelialitis, thrombosis, and angiogenesis in COVID-19	Ackermann M., Verleden S.E., Kuehnel M., et al. (2020)	New England Journal of Medicine	1810
6	Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents	Kampf G., Todt D., Pfaender S., Steinmann E. (2020)	Journal of Hospital Infection	1495
7	Compassionate use of remdesivir for patients with severe COVID-19	Grein J., Ohmagari N., Shin D., Diaz G., et al. (2020)	New England Journal of Medicine	1344
8	The reproductive number of COVID-19 is higher compared to SARS coronavirus	Liu Y., Gayle A.A., Wilder-Smith A., Rocklöv J. (2020)	Journal of Travel Medicine	1286
9	COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review	Bikdeli B., Madhavan M.V., Jimenez D., et al. (2020)	Journal of the American College of Cardiology	1224
10	Crystal structure of SARS-CoV-2 main protease provides a basis for design of improved a-ketoamide inhibitors	Zhang L., Lin D., Sun X., et al. (2020)	Science	1078

The 2019-nCoV has posed a serious global problem. People across the world are directionless to find a way to save themselves from the grasp of the deadly virus. Researchers of almost all the countries are engaged to find the way of prevention of infection, and method of treatment, etc. German researchers have also come forward to carry on the research in this regard. Hoffmann et al., (2020) deeply investigated the existence of any cell or any kind of host in the human body that has an affinity to attract the SARS CoV-2 or if there exist any matters that prevent the access of virus in the human body. They observed that ACE2 accelerates the easy entrance of the virus into the human body. They also demanded that the entry of lethal virus may be blocked by an inhibitor of the cellular series protease TMPRSS2 which is employed by SAERS-CoV-2 for S protein priming. Kampf et al., (2020) inquired whether inanimate things like metal, glass, or plastic are regarded as a carrier of coronavirus or not. They inferred that such inanimate things may persist the virus for up to 9 days. Chemical reagents like ethanol, sodium hypochlorite, and hydrogen peroxide can disinfect the virus within one minute up to a certain percentage. The positivity rate (R_0) is used to represent the speed/rate of virus's transmissibility. Positivity rate of the COVID-19 virus was estimated by Liu et al. (2020). They show that if R_0 is greater than one ($R_0>1$), infection is likely to increase, and if it is less than one ($R_0<1$), infection is going to diminish. According to their estimate, the mean R_0 is 3.28 in mid-February, 2020 which is greater than WHO's estimate. Zhang et al (2020) analyzed the x-ray crystal structure of SARs-CoV-2 in two different crystal forms, at 1.95 and 2.20 Å resolution, to identify the main protease and its complex (M pro or 3CL pro) which cuts the polyproteins translated from viral RNA to yield functional viral proteins. They also tried to provide a useful framework to find pyridine-containing inhibitors to discover anti-coronaviral drugs.

4.9. Australia

Table 17 presents the top fifteen authors, subject area, and institution of Australia based on the TP.

Table 17. Leading authors, subject areas, and institutions in COVID-19 research in Australia

R	Authors	TP	Subject area	TP	Institution	TP
1	Lippi, G.	25	Medicine	3115	University of Melbourne	856
2	MacIntyre, C.R.	25	Social Sciences	1297	Monash University	729
3	Moni, M.A.	24	Biochemistry, Genetics and Molecular Biology	536	The University of Sydney	686
4	Subbarao, K.	23	Environmental Science	438	UNSW Sydney	650
5	Holmes, E.C.	21	Business, Management and Accounting	419	The University of Queensland	535
6	Morawska, L.	20	Immunology and Microbiology	351	Deakin University	280
7	Robinson, P.C.	20	Psychology	348	Faculty of Medicine, Nursing and Health Sciences	274
8	Islam, S.M.S.	19	Nursing	323	University of Technology Sydney	236
9	Ratten, V.	19	Economics, Econometrics and Finance	263	The Australian National University	220
10	Xiang, Y.T.	19	Computer Science	245	The University of Western Australia	220
11	Dua, K.	18	Arts and Humanities	236	Queensland University of Technology	218
12	Savulescu, J.	18	Engineering	233	Griffith University	208
13	Wheatley, A.K.	18	Health Professions	187	The University of Adelaide	192
14	Williamson, D.A.	18	Pharmacology, Toxicology and Pharmaceutics	184	The University of Newcastle, Australia	189
15	Alhumaid, S.	17	Multidisciplinary	176	UNSW Medicine	189

Italian professor Giuseppe Lippi from the University of Verona and Australian Professor C Raina MacIntyre from Kirby Institute are leading jointly in the list of most productive authors in Australian publications related to COVID-19. The performance of Professor Giuseppe Lippi confirms well collaboration of Italy and Australia in COVID-19 related research. The top seven authors in Table 17 have more than or equal to twenty publications. Australian research papers are mostly published in medical journals. A notable 22% of research papers of Australia are published in social science-based journals. The University of Melbourne leads comprehensively among the Australian institutions with 856 publications followed by Monash University which has 729 publications in COVID-19. The top five institutions of Australia in Table 17 have more than 500 publications.

Table 18. List of leading articles of Australia

R	Title	Authors	Journal	Citation
1	Genomic characterisation and epidemiology of 2019 novel coronavirus: implications for virus origins and receptor binding	Lu R., Zhao X., Li J., et al. (2020)	The Lancet	4905
2	A new coronavirus associated with human respiratory disease in China	Wu F., Zhao S., Yu B., et al. (2020)	Nature	3819
3	Multidisciplinary research priorities for the COVID-19 pandemic: a call for action for mental health science	Holmes E.A., O'Connor R.C., Perry V.H., et al. (2020)	The Lancet Psychiatry	1617
4	COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review	Bikdeli B., Madhavan M.V., Jimenez D., et al. (2020)	Journal of the American College of Cardiology	1224
5	Using social and behavioural science to support COVID-19 pandemic response	Bavel J.J.V., Baicker K., Boggio P.S., et al. (2020)	Nature Human Behaviour	1154
6	Structure of Mpro from SARS-CoV-2 and discovery of its inhibitors	Jin Z., Du X., Xu Y., Deng Y., et al. (2020)	Nature	1149
7	Pathophysiology, Transmission, Diagnosis, and Treatment of Coronavirus Disease 2019 (COVID-19): A Review	Wiersinga W.J., Rhodes A., Cheng A.C., Peacock S.J., Prescott H.C.	JAMA - Journal of the American Medical Association	1093

4.10. France

Table 19. Leading authors, subject areas, and institutions in COVID-19 research in France

R	Authors	TP	Subject area	TP	Institution	TP
1	Raoult, D.	46	Medicine	3215	Inserm	1358
2	Lechien, J.R.	40	Biochemistry, Genetics and Molecular Biology	665	AP-HP Assistance Publique - Hopitaux de Paris	886
3	Dyer, O.	36	Immunology and Microbiology	511	CNRS Centre National de la Recherche Scientifique	810
4	Lescure, F.X.	36	Social Sciences	272	Université de Paris	688
5	Lina, B.	34	Nursing	260	Sorbonne Universite	526
6	Colson, P.	33	Environmental Science	228	Universite Paris-Saclay	424
7	Saussez, S.	33	Pharmacology, Toxicology and Pharmaceutics	206	Aix Marseille Université	359
8	La Scola, B.	32	Multidisciplinary	194	Hôpital Universitaire Pitié Salpêtrière	252
9	Gautret, P.	29	Neuroscience	185	Université de Montpellier	227
10	Lagier, J.C.	29	Economics, Econometrics and Finance	173	Université Claude Bernard Lyon 1	221
11	Fafi-Kremer, S.	28	Business, Management and Accounting	169	CHU de Lyon	220
12	Bousquet, J.	27	Psychology	169	Université de Versailles Saint-Quentin-en-Yvelines	210
13	Visseaux, B.	27	Agricultural and Biological Sciences	154	Les Hôpitaux Universitaires de Strasbourg	193
14	Yazdanpanah, Y.	27	Engineering	123	Institut Pasteur, Paris	186
1	Jacob, L.	26	Computer Science	120	Hôpital Bichat-Claude-	176

5					Bernard AP-HP	

Professor Didier Raoult from Aix Marseille Université, France has 46 publications in COVID-19 related research, leads the list of most productive authors in France. Professor J.R. Lechien is the second-ranked author in France with 40 publications in COVID-19 based research. The top eight authors in Table 19 have more than thirty publications. The top three leading subject areas of France in COVID-19 research are '*Medicine*', *'Biochemistry, Genetics and Molecular Biology'*, and *'Immunology and Microbiology'*. The National Institute of Health and Medical Research (Inserm) leads comprehensively among the Australian institutions with 1358 publications followed by AP-HP Assistance Publique - Hopitaux de Paris which has 886 publications in COVID-19. CNRS Centre National de la Recherche Scientifique also shows important presence among the institutions in France. The top five institutions of France in Table 19 have more than 500 publications.

Table 20: List of leading articles of France

R	Title	Authors	Journal	Citation
1	Hydroxychloroquine and azithromycin as a treatment of COVID-19: results of an open-label non-randomized clinical trial	Gautret P., Lagier J.-C., Parola P., et al. (2020)	International Journal of Antimicrobial Agents	2656
2	Compassionate use of remdesivir for patients with severe COVID-19	Grein J., Ohmagari N., Shin D., et al. (2020)	New England Journal of Medicine	1344
3	A SARS-CoV-2 protein interaction map reveals targets for drug repurposing	Gordon D.E., Jang G.M., Bouhaddou M., et al. (2020)	Nature	1291
4	COVID-19 and Thrombotic or Thromboembolic Disease: Implications for Prevention, Antithrombotic Therapy, and Follow-Up: JACC State-of-the-Art Review	Bikdeli B., Madhavan M.V., Jimenez D., et al. (2020)	Journal of the American College of Cardiology	1224
5	High risk of thrombosis in patients with severe SARS-CoV-2 infection: a multicenter prospective cohort study	Helms J., Tacquard C., Severac F., et al. (2020)	Intensive Care Medicine	1089
6	Olfactory and gustatory dysfunctions as a clinical presentation of mild-to-moderate forms of the coronavirus disease (COVID-19): a multicenter European study	Lechien J.R., Chiesa-Estomba C.M., De Siati D.R., et al. (2020)	European Archives of Oto-Rhino-Laryngology	1068

Gautret et al., (2020) assayed whether hydroxychloroquine, and azithromycin are effective or not in lowering the viral load in covid infected patients. Based on a short sample, they observed that hydroxy chlorine helps lessen the viral load. They also inferred that using azithromycin in

conjunction with hydroxychloroquine is more effective. Based on some clinical trials, Helms, et al., (2020) found that CT pulmonary angiography (CTPA) may strongly assist the severe covid patients with high pulmonary embolism (PE). They also showed that lung ultrasonography alone is unable to detect/uncover the proper cause of deterioration of covid patients. CTPA is extremely useful to explore the unknown and peculiar characteristics/symptoms in such cases. Gordon et al., (2020) made a chemo-proteomic analysis to discover effective drugs for the treatment of covid patients. They also stressed the deciphering of the virus's mechanism responsible for it. They expect that their study will show a new avenue to fight against the different viruses along with the coronavirus.

4.11. Leading authors, subject areas, and institutions of remaining 15 countries

Table 21. Leading authors, subject areas, and institutions in COVID-19 research of remaining 15 countries

	R	Authors	TP	Subject area	TP	Institutions	TP
Brazil	1	Giovanetti, M.	33	Medicine	2892	Universidade de São Paulo	1074
	2	Malta, D.C.	28	Social Sciences	504	Fundacao Oswaldo Cruz	409
	3	Rocco, P.R.M.	25	Biochemistry, Genetics and Molecular Biology	487	Universidade Federal de São Paulo	346
	4	Szwarcwald, C.L.	23	Immunology and Microbiology	398	Universidade Federal do Rio de Janeiro	316
	5	Sabino, E.C.	22	Nursing	357	Universidade Federal de Minas Gerais	313
Turkey	1	Karabay, O.	27	Medicine	2570	University of Health Sciences	564
	2	Yıldırım, M.	26	Biochemistry, Genetics and Molecular Biology	369	Hacettepe Üniversitesi	238
	3	Arslan, G.	25	Social Sciences	321	Istanbul Üniversitesi	176
	4	Baleanu, D.	25	Immunology and Microbiology	302	Ankara Üniversitesi	145
	5	Dheir, H.	18	Nursing	191	İstanbul University-Cerrahpaşa Cerrahpaşa Faculty of Medicine	130
Iran	1	Rezaei, N.	75	Medicine	2655	Tehran University of Medical Sciences	885
	2	Tabarsi, P.	40	Biochemistry, Genetics and Molecular Biology	502	Shahid Beheshti University of Medical Sciences	665
	3	Zali, A.	28	Immunology and Microbiology	485	Iran University of Medical Sciences	490
	4	Jamaati, H.	27	Pharmacology, Toxicology and Pharmaceutics	330	Shiraz University of Medical Sciences	348
	5	Marjani, M.	22	Social Sciences	219	Tabriz University of Medical Sciences	241
ud i Ar ab	1	Rabaan, A.A.	40	Medicine	1534	King Saud University	632
	2	Al-Tawfiq,	36	Computer Science	424	King Abdulaziz University	484

		J.A.					
	3	Memish, Z.A.	34	Biochemistry, Genetics and Molecular Biology	369	Imam Abdulrahman Bin Faisal university	229
	4	Dhama, K.	33	Engineering	298	King Saud bin Abdulaziz University for Health Sciences	220
	5	Halwani, R.	28	Social Sciences	289	Taif University	197
Japan	1	Ohmagari, N.	47	Medicine	1770	The University of Tokyo	270
	2	Suzuki, T.	27	Biochemistry, Genetics and Molecular Biology	400	Kyoto University	152
	3	Kinoshita, N.	26	Social Sciences	319	Hokkaido University	123
	4	Nishiura, H.	26	Environmental Science	275	Keio University	96
	5	Yoneoka, D.	22	Immunology and Microbiology	264	National Center for Global Health and Medicine	93
Netherlands	1	Netea, M.G.	37	Medicine	1820	Erasmus MC	341
	2	Haagmans, B.L.	25	Social Sciences	431	Universiteit van Amsterdam	335
	3	van Gils, M.J.	22	Biochemistry, Genetics and Molecular Biology	315	Universiteit Utrecht	272
	4	Koopmans, M.P.G.	21	Immunology and Microbiology	254	Universiteit Maastricht	262
	5	van de Veerdonk, F.L.	21	Environmental Science	196	Amsterdam UMC - University of Amsterdam	258
Switzerland	1	Kaiser, L.	38	Medicine	1825	University of Zurich	388
	2	Akdis, C.A.	27	Biochemistry, Genetics and Molecular Biology	356	University of Bern	328
	3	Eckerle, I.	26	Immunology and Microbiology	258	Hôpitaux Universitaires de Genève	275
	4	Guessous, I.	22	Social Sciences	242	Université de Genève	260
	5	Agache, I.	19	Environmental Science	159	Universitat Basel	246
South Korea	1	Peck, K.R.	27	Agricultural and Biological Sciences	48	Seoul National University	201
	2	Kim, Y.J.	23	Arts and Humanities	44	Seoul National University College of Medicine	164
	3	Kim, S.H.	21	Biochemistry, Genetics and Molecular Biology	281	Yonsei University	132
	4	Bhattacharya, M.	20	Business, Management and Accounting	120	Yonsei University College of Medicine	129
	5	Chakraborty, C.	20	Chemical Engineering	79	University of Ulsan College of Medicine	118
Pakistan	1	Shah, K.	33	Medicine	1018	The Aga Khan University	153
	2	Ullah, I.	21	Social Sciences	217	University of the Punjab	109
	3	Bilal, M.	17	Biochemistry, Genetics and Molecular Biology	201	Quaid-i-Azam University	98
	4	Ahmad, S.	16	Computer Science	194	Dow University of Health Sciences Pakistan	88
	5	Abdeljawad, T.	15	Environmental Science	173	The Aga Khan University Hospital	84
South Africa	1	Wiysonge, C.S.	23	Medicine	1017	University of Cape Town	370
	2	Giovanetti, M.	16	Social Sciences	511	University of the Witwatersrand, Johannesburg	300

	3	Nachega, J.B.	16	Biochemistry, Genetics and Molecular Biology	210	University of KwaZulu-Natal	292
	4	Zumla, A.	16	Business, Management and Accounting	160	Stellenbosch University	284
	5	de Oliveira, T.	16	Arts and Humanities	133	University of Pretoria	230
Poland	1	Agache, I.	20	Medicine	1125	Medical University of Warsaw	216
	2	Banach, M.	20	Social Sciences	266	Wroclaw Medical University	171
	3	Wierzba, W.	20	Environmental Science	265	Jagiellonian University Medical College	145
	4	Jutel, M.	17	Biochemistry, Genetics and Molecular Biology	226	Poznan University of Medical Sciences	145
	5	Klimek, L.	16	Immunology and Microbiology	145	Slaski Uniwersytet Medyczny w Katowicach	142
Indonesia	1	Pranata, R.	49	Medicine	801	Universitas Indonesia	248
	2	Harapan, H.	41	Social Sciences	493	Universitas Airlangga	180
	3	Lim, M.A.	29	Pharmacology, Toxicology and Pharmaceutics	189	Universitas Padjadjaran	142
	4	Huang, I.	27	Business, Management and Accounting	183	Universitas Gadjah Mada	115
	5	Kurniawan, A.	23	Biochemistry, Genetics and Molecular Biology	155	Universitas Pelita Harapan	87
Egypt	1	Mostafa, A.	20	Medicine	1021	Cairo University	410
	2	Batiha, G.E.S.	17	Biochemistry, Genetics and Molecular Biology	267	Mansoura University	190
	3	Abdel-Daim, M.M.	16	Pharmacology, Toxicology and Pharmaceutics	190	Alexandria University	182
	4	Hassanien, A.E.	16	Computer Science	177	Ain Shams University	171
	5	Hetta, H.F.	16	Immunology and Microbiology	164	Zagazig University	146
Belgium	1	Lechien, J.R.	51	Medicine	1281	KU Leuven	397
	2	Saussez, S.	41	Biochemistry, Genetics and Molecular Biology	254	Universiteit Gent	246
	3	Neyts, J.	29	Immunology and Microbiology	210	Universiteit Antwerpen	241
	4	Colebunders, R.	26	Social Sciences	186	Université Libre de Bruxelles	238
	5	Vaira, L.A.	26	Environmental Science	123	Université Catholique de Louvain	173
Sweden	1	Pakpour, A.H.	27	Medicine	1088	Karolinska Institutet	568
	2	Lin, C.Y.	24	Social Sciences	273	Karolinska Universitetssjukhuset	265
	3	Griffiths, M.D.	22	Biochemistry, Genetics and Molecular Biology	236	Uppsala Universitet	219
	4	Frithiof, R.	20	Immunology and Microbiology	191	Lunds Universitet	210
	5	Hultström, M.	19	Environmental Science	161	Göteborgs Universitet	185

Table 21 highlights the leading authors, subject areas, and institutions in COVID-19 research of the remaining 15 countries namely Brazil, Turkey, Iran, Saudi Arabia, Japan, Netherlands, Switzerland, South Korea, Pakistan, South Africa, Poland, Indonesia, Egypt, Belgium, and Sweden. We can see that the subject area 'medicine' has the highest number of publications of all countries which is quite natural as the entire world is working hard to overcome the health crisis by seeking medicine or vaccine as early as feasible. In terms of paper publication, N. Ohmagari of Iran holds first place followed by J.R. Lechien of Belgium contributing 75 and 51 papers respectively. During this short time R. Pranata of Indonesia produced 49 papers securing the third position, and the remaining authors from those 15 countries contributed papers ranging from 16 to 40 in number. Universidade de São Paulo of Brazil put a good impression on carrying on the COVID-19 research. The institute submitted a total of 1074 papers. In terms of paper publication, the Tehran University of Medical Sciences is not also far behind. The institute developed 885 papers in this area. Among the 15 countries, these two institutes came in first and second place, respectively.

4.12. Keyword analysis of top five countries

Table 22: List of Keywords of top five countries according to the published papers

R	USA		UK		CHINA		ITALY		INDIA	
	Keyword	**TP**	**Keyword**	**TP**	**Keyword**	**TP**	**Keyword**	**TP**	**Keyword**	**TP**
1	COVID-19	26343	COVID-19	9921	COVID-19	10161	COVID-19	8142	COVID-19	6689
2	Human	24283	Human	8705	Human	9260	Human	7679	Human	5014
3	Humans	20898	Humans	7223	Humans	7690	Humans	6155	Coronavirus Disease 2019	3819
4	Coronavirus Disease 2019	15726	Coronavirus Disease 2019	5799	Coronavirus Disease 2019	6783	Coronavirus Disease 2019	5734	Humans	3319
5	Pandemic	14942	Pandemic	5709	Article	5684	Pandemic	4701	Pandemic	3297
6	SARS-CoV-2	13366	Article	4707	SARS-CoV-2	5167	Article	4527	SARS-CoV-2	2995
7	Article	13091	SARS-CoV-2	4591	Pandemic	4939	SARS-CoV-2	4425	Article	2691
8	Pandemics	11272	Pandemics	4033	Female	4730	Pandemics	3518	Pandemics	1774
9	Female	9279	Female	3354	Male	4667	Female	3451	India	1718
10	Male	8877	Male	3213	China	4517	Male	3429	Severe Acute Respiratory Syndrome Coronavirus 2	1599
11	Adult	8127	Adult	2896	Pandemics	4234	Adult	2830	Female	1287
12	Priority Journal	6825	Virus Pneumonia	2269	Adult	4186	Italy	2769	Review	1277
13	Virus Pneumonia	6734	Priority Journal	2251	Virus Pneumonia	3330	Virus Pneumonia	2447	Male	1245

14	Coronavirus Infection	6622	Coronavirus Infection	2230	Coronavirus Infection	3155	Pneumonia, Viral	2309	Priority Journal	1216
15	Coronavirus Infections	6602	Coronavirus Infections	2224	Pneumonia, Viral	3149	Coronavirus Infections	2282	Adult	1164
16	Pneumonia, Viral	6528	Pneumonia, Viral	2190	Coronavirus Infections	3146	Coronavirus Infection	2281	Nonhuman	1159
17	Severe Acute Respiratory Syndrome	5512	Middle Aged	1909	Middle Aged	3082	Aged	2252	Coronavirus	1143
18	Betacoronavirus	5343	Epidemiology	1903	Betacoronavirus	2710	Severe Acute Respiratory Syndrome Coronavirus 2	2202	Virus Pneumonia	1093
19	Middle Aged	5336	Aged	1871	Severe Acute Respiratory Syndrome Coronavirus 2	2688	Middle Aged	2122	Coronavirus Infection	1070
20	Aged	4945	Betacoronavirus	1827	Aged	2560	Priority Journal	1987	Coronavirus Infections	1054
21	Epidemiology	4860	United Kingdom	1668	Controlled Study	2538	Betacoronavirus	1950	Pneumonia, Viral	1023
22	United States	4758	Major Clinical Study	1642	Major Clinical Study	2469	Major Clinical Study	1647	Betacoronavirus	932
23	Controlled Study	4488	Severe Acute Respiratory Syndrome Coronavirus 2	1642	Priority Journal	2378	Controlled Study	1410	Virology	795
24	Procedures	4411	Controlled Study	1615	Virology	2107	Virology	1400	Controlled Study	707
25	Virology	4187	Coronavirus	1494	Retrospective Study	2046	Epidemiology	1342	Epidemiology	695

According to the number of articles published, in Table 22 we have considered 25 keywords from the top five countries namely the USA, UK, China, Italy, and India, and sorted the keywords in descending order. The keyword COVID-19 appears to be near the top of the search results in each of the countries. It is quite natural because all the research papers are focussing here on different aspects of the COVID-19 virus. It is 26343 in the USA. Then proceed to China, U.K., Italy, and India in that order. Keywords like *human*, *humans*, *coronavirus disease 2019*, *SARSCOV2*, *pandemic*, and *male and female* have been used frequently. Since the clinical trials have been conducted on people of various ages, the keywords *aged*, and *middle aged* has been used frequently. In terms of the number of publications, the keyword *virology* has appeared 4187 times in the United States, however it is not on the list in the United Kingdom. The keyword *COVID-19* ranks first in all five countries, with a significant difference in number between the United States and the remaining four. The differences between the United States and the United Kingdom, China, Italy, and India are 16422, 16182, 18201, and 19654, respectively. The keyword *retrospective study* has been added to the Chinese keyword list once more,

however, it is not included in the list of 25 keywords from the other four nations. The Table 22 reveals that the keywords *review* and *non-human* are only found in India's list of keywords. Again, it is observed that in the Indian keyword list, the term *epidemiology* appears only 695 times and is placed last in the Table 22, whereas in the United States, the term *virology* appears at the final position and has a TP of 4187. Keyword, *Major Clinical Study* is not on the list for the United States or India, but it is on the list for the remaining three countries: the United Kingdom, China, and Italy. The Table 22 also shows that almost all of the keywords have significant numerical differences between the United States and the remaining four other countries.

5. Discussion and analysis of important findings

***i*)** USA, U.K., China, Italy, and India have all made a significant contribution to COVID-19 research. Research on COVID-19 is being conducted in a variety of directions, which is a good sign of interdisciplinary research. In China it is observed infected patients have a history of going to or working local seafood markets in Wuhan city. It is observed three authors of China have published three papers that have more than 10000 citations within a very short span of time. It has been observed by some authors that the quality of the environment has significantly improved due to the long duration of lockdown around the world which is a positive side of lockdown.

***ii*)** We have made an important observation. *The Lancet* and *New England Journal of Medicine*, according to the Scopus database, are the pioneering journal in terms of citation ensuring their excellence. *The Lancet* remains in the highest position while *New England Journal of Medicine* secures the second position. Kappa et. al., (2021) used the web of science database to observe that *New England Journal of Medicine* and *The Lancet* occupies the first and second position respectively. Therefore, it can be inferred that the journals *The Lancet*, and *New England Journal of Medicine* are mostly preferred and high-quality journals to the researchers irrespective of Scopus or web of science database.

***iii*) Leading collaborative research works:**

Leading articles of the top ten countries, we see that some articles are simultaneously enlisted in the list of the leading articles of several countries. Bikdeli et al., (2020) published their paper in

the *Journal of American College of Cardiology* that received 1224 citations. This article enlisted in the lists of the leading articles of five countries: Italy, Spain, Germany, Australia, and France. Grein et al., (2020) produced their paper in the famous journal *New England Journal of Medicine* gaining 1344 citations. This work is listed in the lists of the leading articles of four different countries like Italy, Canada, Spain, and France. Lechien et al., (2020) wrote their paper in the *European Archives of Oto-Rhino-Laryngology* that received 1068 citations. They are simultaneously listed in the four countries namely Italy, Canada, Spain, and France. Bavel et al., (2020) published their paper in *Nature Human Behaviour* receiving 1154 citations. They are listed in two different countries: Canada, and Australia. Holms et al., (2020) submitted their paper in *The Lancet Psychiatry* that received a total of 1617 citations. It is concurrently mentioned in the lists of the leading articles of two countries the U.K., and Australia. Paper developed by Wu, F. et al., (2020) is published *Nature* having 3815 citations. It is concurrently mentioned in the lists of the leading articles of two countries China, and Australia. Polack et al., (2020) produced their paper in *New England Journal of Medicine* with 2180 citations. It is listed in both U.K. and Germany. Beigel et al., (2020) published a manuscript in the prestigious *New England Journal of Medicine*, which received 2186 citations. They are concurrently listed in three different countries namely the U.K., Spain, and Germany. Wölfel et al., (2020) submitted their article in 'Nature' that gained 2685 citations. It is simultaneously mentioned in two countries U.K., and Germany. With citations 4905, Lu et al., (2020) published their article in the prestigious medical journal *The Lancet.* China, and Australia are the two countries where it is listed. Cao et al., (2020) wrote their manuscript in *New England Journal of Medicine* which got 2668 citations. They are associated with two countries: the U.K., and China. Mao et al., (2020) has produced their paper in *JAMA Neurology* that received 2655 citations. They are listed in two countries at the same time: the USA, and China.

***iv*) Top collaborating authors**

Some authors appeared simultaneously in the list of leading authors in COVID-19 research of 25 countries. Italian professor Giuseppe Lippi from the University of Verona is leading simultaneously in three countries: USA, Italy, and Australia with 63, 87, and 25 publications respectively. Professor Giuseppe Lippi has a total of 87 publications in COVID-19 related research and among these publications, he collaborates 63 with American authors and 25 with

Australian authors. Saudi Arabian author Ali A. Rabaan is leading in two different countries: India, and Saudi Arabia. Both Germany and Netherlands enlisted M.G. Netea, whereas J. Bousquetis listed in Germany, and France. Again, Dyer is attached with France as well as Canada where, L. Jacob is also enlisted for both France and Spain. Both the USA and Saudi Arabia contain the author J.A. Ai-Tawfiq. The Indian author K. Dhama is included in the list of Saudi Arabia also. R. Halwani is associated with Canada, and Saudi Arabia while L. Agacheis linked to Spain, Switzerland, and Poland. Again, M. Giovanetti is listed in two different countries namely South Africa, and Brazil where L. Klimek is linked to Germany, and Poland. French and Belgium are related with S. Saussez where M. D. Griffiths is listed in both the United Kingdom and Sweden. J.R. Lechien. is known for his work in France, Spain, and Belgium where A. Zumla is connected with the United Kingdom, and South Africa. Both the countries the United Kingdom, and Spain enlisted the author L. Smith where Z.A. Memish, has ties to the United States and Saudi Arabia. M. Bilal is linked to China along with Italy and both the USA and Italy include B.M. Henry.

***v*) Different insights of using the drug remdesivir**

Jin et al., (2020) were unable to reach a definite conclusion about the efficacy of remdesivir. They guessed that early application of remdesivir may be effective but they are in doubt about the outcomes of late treatment. They think that more exploration is required in this matter. Grein et al., (2020) concluded that this drug may take an effective role for severe patients. After careful observations of hospitalized patients admitted to ten hospitals, Wang et al., (2020) inferred that the remdesivir drug has no significant effect on the covid infected patients. Wiersinga et al., (2000) observed that remdesivir is able in lowering the recovery time for non-severe patients. Beigel et al., (2020) took into account of 1062 patients among which 541 are given remdesivir while the remaining 521 were applied placebo. It is observed that patients who received remdesivir recovered faster than those who are treated with a placebo. The drug is also helpful in reducing respiratory tract infections.

***vi)* Glimpse of mathematics in COVID-19 related research**

Here we highlight some papers which contributes mathematical implications relevant to the topic. Aydin and Tirkolaee (2021) discussed the country level calibration and prediction based

on some well-known models like logistic model, exponential model, Gompertz model, SIR model and SEIR model using real data from different countries. They calculated goodness of fit and compared the efficacy of the above-mentioned models.

In the logistic model the total number of infected is calculated by the formula

$I_t^{(1)} = \frac{c}{1+e_a^{t-b}}$ where a, b, and c are the infection speed, inflection point (the point at which the maximum increase in the number of infected occurs), and the estimated number of infected once the pandemic ends respectively.

Now, $I''(t) = \frac{c\gamma(1-\gamma^2)}{a^2(1+\gamma)^4}$ where $\gamma(t) = e^{-(t-b)/a}$

$I''(t)=0$ gives $\gamma=1$ which is possible only when $t=b$ or $t \to \infty$ and b is said to be point of inflection. When $t \to \infty$, $I_t = c$ giving horizontal asymptote and the flatten level of I_t.

That means $I_t' = \frac{c\gamma}{a(1+\gamma)^2} = 0 \Rightarrow t \to \infty$

In the exponential model, the total number of infected is calculated as $I_t^{(2)} = a.\, e^{b(t-c)}$ where a, b, c are the initial number of infected growth rate, and starting date of infection. But this model does not converge when it becomes larger.

Next, they consider 'Gompertz Growth Model'. The number of infections is calculated by the formula, $I_t^{(2)} = a.\, e^{-b(t-c)}$ where a, b, c are the upper bounds of total number of infected, the growth rate, and the location parameter respectively. The maximum rate of increase in the number of infected occurs at $t = \frac{\ln b}{c}$ obtained from the differential equation $I'' = Ib^2c^2e^{-ct}(e^{-ct} - \frac{1}{b}) = 0$

For calibration they used Python SciPy along with the Scikit Library.

In the SIR model, the systems of quadratic equations are

$$dS_t = -\beta S_t I_t^{(4)} dt$$
$$dI_t^{(4)} = (\beta S_t - \gamma) I_t^{(4)} dt$$
$$dR_t = \gamma I_t^{(4)} dt$$

Where β and γ are the transmission and recovery rates respectively, and $\lim_{t\to\infty} S_t$, $\lim_{t\to\infty} I_t$ and $\lim_{t\to\infty} R_t$ exist.

SEIR model is the extension of SIR model. In this model, the system of differential equations are given by

$$dS_t = -\beta S_t I_t^{(5)} dt$$
$$dE_t = (\beta S_t I_t^{(5)} - \theta E_t) dt$$
$$dI_t^{(5)} = (\theta E_t - \gamma I_t^{(5)}) dt$$
$$dR_t = \gamma I_t^{(5)} dt$$

Where β and γ are the transmission and the recovery rates respectively, and θ is the incubation rate.

To examine the production, distribution, and recycling of face masks during the COVID-19 pandemic, a mathematical model of a sustainable Closed Loop Supply Chain Network (CLSCN) has been developed by Tirkolace et al. (2021). A multi-objective **Mixed Integer Linear Programming** (MILP) has been proposed to address the allocation, supply, production, distribution, collection, quarantine, recycling, reuse, and disposal within the proposed networks. They considered two types of supply chain networks-forward supply chain and reverse supply chain. Forward supply chain networks include different levels of suppliers, factories, distribution centers, customer centers, and reverse supply chain network includes recycling centers, collection centers, quarantine centers, and disposal centers. The basic objectives were to minimize human risks as much as possible using sustainable face masks along with the minimization of other cost which includes establishment cost, transportation cost and employment cost, and total environmental pollution within CLSCN keeping in the mind the social, economic and environmental impact. They proposed two multi-objective meta heuristic algorithm of **Multi-Objective Grey Wolfe Optimization (MOGWO)**, and NAGA-II to

overcome the complexity of the problem and validated the outcome of the proposed model by using real case study in Tehran of Iran. It is almost impossible to determine the future trends of the COVID-19 virus due to its presence of some stochastic parameters. Khalilpourazari et al (2021) applied a new algorithm **named Gradient -based Grey Wolfe Optimizer (GGWO)** in the prediction of future trends of SARS-CoV-2 and demanded that the had proved its efficacy in the United States. They also hope that the proposed method will enable the researchers to solve the complex function in future. Like Particle Swarm optimization (PSO), the GGWO Starts with initial population and next find the dominant members of the wolves. In this way the wolves update their position in the solution space near the target. Mondal and Roy (2021) presented a sustainable opened and closed supply chain (SOCLSC) planning to manage supply among production centers and various hospitals during the sudden outbreak of COVID-19 pandemic. A **multi objective mixed integer programming** (MOMIP) describing a two-stage SOCLSC in an uncertain environment is applied to solve the proposed model. The primary objective was to minimize the total cost (production cost, holding cost, and distribution cost), total time, and the weighted backlog amount as well as to maximize the social impact by increasing job opportunities in production system, proper handling of produced items, and optimal distribution of the available items. To deal with the **uncertainty** in different scenarios, they used **Robust Optimization (RO**) approach, and applied **Augmented Weighted Tchebycheff Method (AWTM)** to solve the model.

6. Conclusions

This bibliometric analysis of COVID-19 was designed with great care. Through this study, we try to depict a summary of global research progress on the current and burning issue. That is, we are aware of the research position to solve the present global health calamity. Here we consider twenty (25) leading countries across six continents that are actively involved in COVID-19 research. We have included different parameters to frame our study like TP, H-index, citation threshold, leading authors, subject area, institutions in terms of TP of those countries, and most commonly used keywords with TP of the top five countries to construct our analysis.

After careful study, we see that the USA is the leading country followed by U.K. and China but with respect to H-index China remains in a better position. The keyword *COVID-19* is mostly used, and the highest numbers of papers have been developed in the area of *medicine*. The

Harvard Medical School of the U.K. contributed the highest number of papers followed by the University of Toronto of Canada and Huazhong University of Science and Technology respectively. Professor K Dhama India of the published highest number of papers while C. Huang of China received the highest number of citations followed by W. Guan of the same country. It is also seen that *The Lancet*, *New England Journal of Medicine*, *Journal of American Medical Association (JAMA)*, *The Lancet Psychiatry*, and *Nature* are the pioneering journals attractive to the researchers for publication of their valuable work. All these journals are working hard to bring the essence of research to the world as soon as feasible.

We may suggest the following research fields that may be promising in near future. (i) Use of AI in research COVID-19 research. (ii) Use of data analysis to find several factors behind the infection. More exploration is required to find whether it is event-specific or not. (iii) Emphasis should be given to Interdisciplinary research, which may disclose/reveal a new perspective. (iv) Effects of prolonged lockdown on the environment, education, and economy. (v) Impact of COVID-19 in the change of human development index. (vi) how does the situation affect the supply chain logistics?

This work has following major limitation. A document will be considered for a country if one or more authors used affiliation of that country. Suppose a document has N authors from M different countries then it will be considered in the account of all M countries associated with its authors. Thus, a document may be possible to display in the account of more than one country. We have used Scopus database and results are based on the outcome of the database.

References

Ackermann, M., Verleden, S. E., Kuehnel, M., et al., (2020). Pulmonary vascular endothelialitis, thrombosis, and angiogenesis in COVID-19. *New England Journal of Medicine*, 383(2), 120-128. doi:10.1056/NEJMoa2015432.

Aydin, N. S., & Tirkolaee, E. B. (2022). Modelling and Predicting The Growth Dynamics Of Covid-19 Pandemic: A Comparative Study Including Turkey. *Journal of Turkish Operations Management*, *6*(1), 943-954.

Babaee Tirkolaee, E., & Aydın, N. S. (2021). A sustainable medical waste collection and transportation model for pandemics. *Waste Management & Research*, *39*(1), 34-44.

Bavel, J. J. V., Baicker, K., Boggio, P. S., et al., (2020). Using social and behavioural science to support COVID-19 pandemic response. *Nature Human Behaviour*, 4(5), 460-471. doi:10.1038/s41562-020-0884-z

Beigel, J. H., Tomashek, K. M., Dodd, L. E., Mehta, A. K., Zingman, B. S., Kalil, A. C., . . . Lane, H. C. (2020). Remdesivir for the treatment of COVID-19 — final report. *New England Journal of Medicine*, 383(19), 1813-1826. doi:10.1056/NEJMoa2007764

Bikdeli, B., Madhavan, M. V., Jimenez, D., et al., (2020). COVID-19 and thrombotic or thromboembolic disease: Implications for prevention, antithrombotic therapy, and follow-up: JACC state-of-the-art review. *Journal of the American College of Cardiology*, 75(23), 2950-2973. doi: 10.1016/j.jacc.2020.04.031

Cao, B., Wang, Y., Wen, D., et al., (2020). A trial of lopinavir-ritonavir in adults hospitalized with severe COVID-19. *New England Journal of Medicine*, 382(19), 1787-1799. doi:10.1056/NEJMoa2001282

Chan, J. F., Yuan, S., Kok, K. et al., (2020). A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: A study of a family cluster. *The Lancet*, 395(10223), 514-523. doi:10.1016/S0140-6736(20)30154-9

Chen, N., Zhou, M., Dong, X., et al., (2020). Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: A descriptive study. *The Lancet*, 395(10223), 507-513. doi:10.1016/S0140-6736(20)30211-7

Chinazzi, M., Davis, J. T., Ajelli, M., et al., (2020). The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science*, 368(6489), 395-400. doi:10.1126/science. aba9757

Chu, D. K., Akl, E. A., Duda, S., et al., (2020). Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: A systematic review and meta-analysis. *The Lancet*, 395(10242), 1973-1987. doi:10.1016/S0140-6736(20)31142-9

Emanuel, E. J., Persad, G., Upshur, R., et al., (2020). Fair allocation of scarce medical resources in the time of COVID-19. *New England Journal of Medicine*, 382(21), 2049-2055. doi:10.1056/NEJMsb2005114

Gautret, P., Lagier, J., Parola, P., et al., (2020). Hydroxychloroquine and azithromycin as a treatment of COVID-19: Results of an open-label non-randomized clinical trial. *International Journal of Antimicrobial Agents*, 56(1) doi: 10.1016/j.ijantimicag.2020.105949

Ghadir, A. H., Vandchali, H. R., Fallah, M., & Tirkolaee, E. B. (2022). Evaluating the impacts of COVID-19 outbreak on supply chain risks by modified failure mode and effects analysis: a case study in an automotive company. *Annals of Operations Research*, 1-31.

Gordon, D. E., Jang, G. M., Bouhaddou, M., et al., (2020). A SARS-CoV-2 protein interaction map reveals targets for drug repurposing. *Nature*, 583(7816), 459-468. doi:10.1038/s41586-020-2286-9

Grasselli, G., Zangrillo, A., Zanella, A., et al., (2020). Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 admitted to ICUs of the Lombardy region, Italy. *JAMA - Journal of the American Medical Association*, 323(16), 1574-1581. doi:10.1001/jama.2020.5394

Grein, J., Ohmagari, N., Shin, D., et al., (2020). Compassionate use of remdesivir for patients with severe COVID-19. *New England Journal of Medicine*, 382(24), 2327-2336. doi:10.1056/NEJMoa2007016

Guan, W., Ni, Z., Hu, Y., et al., (2020). Clinical characteristics of coronavirus disease 2019 in China. *New England Journal of Medicine*, 382(18), 1708-1720. doi:10.1056/NEJMoa2002032

Helms, J., Tacquard, C., Severac, F., et al., (2020). High risk of thrombosis in patients with severe SARS-CoV-2 infection: A multicenter prospective cohort study. *Intensive Care Medicine*, 46(6), 1089-1098. doi:10.1007/s00134-020-06062-x

Hoffmann, M., Kleine-Weber, H., Schroeder, S., et al., (2020). SARS-CoV-2 cell entry depends on ACE2 and TMPRSS2 and is blocked by a clinically proven protease inhibitor. *Cell*, 181(2), 271-280.e8. doi: 10.1016/j.cell.2020.02.052

Holmes, E. A., O'Connor, R. C., Perry, V. H., et al., (2020). Multidisciplinary research priorities for the COVID-19 pandemic: A call for action for mental health science. The Lancet Psychiatry, 7(6), 547-560. doi:10.1016/S2215-0366(20)30168-1

Holshue, M. L., DeBolt, C., Lindquist, S., et al., (2020). First case of 2019 novel coronavirus in the United States. *New England Journal of Medicine*, 382(10), 929-936. doi:10.1056/NEJMoa2001191

Hossain, M. M., Sarwar, S. A., McKyer, E. L. J., & Ma, P. (2020). Applications of artificial intelligence technologies in COVID-19 research: A bibliometric study. *Preprints* **2020**, 2020060161 (doi: 10.20944/preprints202006.0161.v1)

Huang, C., Wang, Y., Li, X., et al., (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *The Lancet*, 395(10223), 497-506. doi:10.1016/S0140-6736(20)30183-5

Jin, Z., Du, X., Xu, Y., et al., (2020). Structure of mpro from SARS-CoV-2 and discovery of its inhibitors. *Nature*, 582(7811), 289-293. doi:10.1038/s41586-020-2223-y

Kampf, G., Todt, D., Pfaender, S., & Steinmann, E. (2020). Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. *Journal of Hospital Infection*, 104(3), 246-251. doi: 10.1016/j.jhin.2020.01.022

Khalilpourazari, S., Doulabi, H. H., Çiftçioğlu, A. Ö., & Weber, G. W. (2021). Gradient-based grey wolf optimizer with Gaussian walk: Application in modelling and prediction of the COVID-19 pandemic. *Expert Systems with Applications*, 177, 114920.

Kappi, M., Sab, M. C., Biradar, B. S., & Bagalkoti, V. T. (2021). Bibliometric Study of World COVID-19 Publication Output. Shanlax International Journal of Arts, *Science and Humanities*, 8(3), 86-95.

Lechien, J. R., Chiesa-Estomba, C. M., De Siati, D. R., et al., (2020). Olfactory and gustatory dysfunctions as a clinical presentation of mild-to-moderate forms of the coronavirus disease (COVID-19): A multicenter European study. *European Archives of Oto-Rhino-Laryngology*, 277(8), 2251-2261. doi:10.1007/s00405-020-05965-1

Liu, Y., Gayle, A. A., Wilder-Smith, A., & Rocklöv, J. (2020). The reproductive number of COVID-19 is higher compared to SARS coronavirus. Journal of Travel Medicine, 27(2) doi:10.1093/jtm/taaa021

Lu, R., Zhao, X., Li, J., et al., (2020). Genomic characterisation and epidemiology of 2019 novel coronavirus: Implications for virus origins and receptor binding. *The Lancet*, 395(10224), 565-574. doi:10.1016/S0140-6736(20)30251-8

Mao, L., Jin, H., Wang, M., et al., (2020). Neurologic manifestations of hospitalized patients with coronavirus disease 2019 in Wuhan, China. *JAMA Neurology*, 77(6), 683-690. doi:10.1001/jamaneurol.2020.1127

Mondal, A., & Roy, S. K. (2021). Multi-objective sustainable opened-and closed-loop supply chain under mixed uncertainty during COVID-19 pandemic situation. *Computers & Industrial Engineering*, 159, 107453.

Nicola, M., Alsafi, Z., Sohrabi, C., et al., (2020). The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *International Journal of Surgery*, 78, 185-193. doi: 10.1016/j.ijsu.2020.04.018

Polack, F. P., Thomas, S. J., Kitchin, N., et al., (2020). Safety and efficacy of the BNT162b2 mRNA COVID-19 vaccine. *New England Journal of Medicine*, 383(27), 2603-2615. doi:10.1056/NEJMoa2034577

Rajkumar, R. P. (2020). COVID-19 and mental health: A review of the existing literature. *Asian Journal of Psychiatry*, 52 doi: 10.1016/j.ajp.2020.102066

Remuzzi, A., & Remuzzi, G. (2020). COVID-19 and italy: What next? *The Lancet*, 395(10231), 1225-1228. doi:10.1016/S0140-6736(20)30627-9

Richardson, S., Hirsch, J. S., Narasimhan, M., et al., (2020). Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York city area. *JAMA - Journal of the American Medical Association*, 323(20), 2052-2059. doi:10.1001/jama.2020.6775

Rodriguez-Morales, A. J., Cardona-Ospina, J. A., Gutiérrez-Ocampo, E., et al., (2020). Clinical, laboratory and imaging features of COVID-19: A systematic review and meta-analysis. *Travel Medicine and Infectious Disease*, 34, 101623.

Rothan, H. A., & Byrareddy, S. N. (2020). The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *Journal of Autoimmunity*, 109 doi: 10.1016/j.jaut.2020.102433

Singhal, T. (2020). A review of coronavirus disease-2019 (COVID-19). *Indian Journal of Pediatrics*, 87(4), 281-286. doi:10.1007/s12098-020-03263-6

Sohrabi, C., Alsafi, Z., O'Neill, N., et al., (2020). World health organization declares global emergency: A review of the 2019 novel coronavirus (COVID-19). *International Journal of Surgery*, 76, 71-76. doi: 10.1016/j.ijsu.2020.02.034

Su, M., Xu, S., & Weng, J. (2021). A bibliometric study of COVID-19 researches in Web of Science. *Pharmacological Research*, 169, 105664.

Tay, M. Z., Poh, C. M., Rénia, L., MacAry, P. A., & Ng, L. F. P. (2020). The trinity of COVID-19: Immunity, inflammation and intervention. *Nature Reviews Immunology*, 20(6), 363-374. doi:10.1038/s41577-020-0311-8

Tirkolaee, E. B., Goli, A., Ghasemi, P., & Goodarzian, F. (2022). Designing a sustainable closed-loop supply chain network of face masks during the COVID-19 pandemic: Pareto-based algorithms. *Journal of Cleaner Production*, 333, 130056.

Vasantha Raju, N., & Harinarayana, N. S. (2020). Indian Clinical Trials on COVID-19: A Review of Clinical Trials Registry of India (CTRI). Available at SSRN 3674093.

Wan, Y., Shang, J., Graham, R., Baric, R. S., & Li, F. (2020). Receptor recognition by the novel coronavirus from Wuhan: An analysis based on decade-long structural studies of SARS coronavirus. *Journal of Virology*, 94(7) doi:10.1128/JVI.00127-20

Wang, Y., Zhang, D., Du, G., et al., (2020). Remdesivir in adults with severe COVID-19: A randomised, double-blind, placebo-controlled, multicentre trial. *The Lancet*, 395(10236), 1569-1578. doi:10.1016/S0140-6736(20)31022-9

Wiersinga, W. J., Rhodes, A., Cheng, A. C., Peacock, S. J., & Prescott, H. C. (2020). Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): A review. *JAMA - Journal of the American Medical Association*, 324(8), 782-793. doi:10.1001/jama.2020.12839

Wölfel, R., Corman, V. M., Guggemos, W., et al., (2020). Virological assessment of hospitalized patients with COVID-2019. *Nature*, 581(7809), 465-469. doi:10.1038/s41586-020-2196-x

Wu, C., Chen, X., Cai, Y., et al., (2020). Risk factors associated with acute respiratory distress syndrome and death in patients with coronavirus disease 2019 pneumonia in Wuhan, China. *JAMA Internal Medicine*, 180(7), 934-943. doi:10.1001/jamainternmed.2020.0994

Wu, F., Zhao, S., Yu, B., et al., (2020). A new coronavirus associated with human respiratory disease in China. *Nature*, 579(7798), 265-269. doi:10.1038/s41586-020-2008-3

Xu, Z., Shi, L., Wang, Y., et al., (2020). Pathological findings of COVID-19 associated with acute respiratory distress syndrome. *The Lancet Respiratory Medicine*, 8(4), 420-422. doi:10.1016/S2213-2600(20)30076-X

Zhang, L., Lin, D., Sun, X., et al., (2020). Crystal structure of SARS-CoV-2 main protease provides a basis for design of improved a-ketoamide inhibitors. *Science*, 368(6489), 409-412. doi:10.1126/science. abb3405

Zhou, F., Yu, T., Du, R., et al., (2020). Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: A retrospective cohort study. *The Lancet*, 395(10229), 1054-1062. doi:10.1016/S0140-6736(20)30566-3

Zhou, P., Yang, X, Wang, X., et al., (2020). A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*, 579(7798), 270-273. doi:10.1038/s41586-020-2012-7

Zhu, N., Zhang, D., Wang, W., et al., (2020). A novel coronavirus from patients with pneumonia in China, 2019. *New England Journal of Medicine*, 382(8), 727-733. doi:10.1056/NEJMoa2001017