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Analyzing research trends and patterns on COVID-19 vaccine hesitancy: A bibliometric study from 2021 to 2022

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ABSTRACT

Objective: To analyze worldwide research trends and patterns on COVID-19 vaccine hesitancy (VH) for the study period from January 2021 to December 2022.

Materials and methods: Current descriptive bibliometric study used SciVerse Scopus to retrieve relevant articles.

Results: The search strategy found 2,886 articles. Scholars from the United States participated in one-third of the retrieved articles. International research collaboration in the field was relatively strong. The retrieved articles focused on healthcare workers, epidemiologic studies, and misinformation. In addition to "*Vaccine*" and "*Vaccines*" journals, *Lancet* and *BMJ* journals had a leading role in the emergence of the topic. Leading global universities such as *Harvard University, Johns Hopkins University*, and *University College London* were most prolific in publishing articles on the topic.

Conclusions: All countries and regions need information on VH to increase public awareness and counteract antivaccination movements.

Keywords: COVID-19, vaccine hesitancy, scientific publications, Scopus, bibliometric analysis

INTRODUCTION

There is overwhelming scientific evidence that vaccination is an effective and safe option for the control and treatment of infectious diseases [1, 2]. Prophylactic vaccination programs eliminated and controlled several serious infectious diseases. World Health Organization (WHO) estimated that two-three million deaths are prevented by vaccination every year [3]. Despite reported safety and efficacy, a substantial minority of people refuse or are hesitant to be vaccinated for religious, political, or cultural reasons [4]. Vaccine hesitancy (VH) is a global phenomenon supported by anti-vaccination groups, fake news, and misinformation spread through social media [5-7]. In 1998, the antivaccination movement gained momentum with the results of a fraud study that linked the MMR vaccine with the development of autism in children [8, 9]. The autism study ignited the antivaccination movement and created concern and confusion in the general public [10, 11]. Increasing public knowledge and awareness about the effectiveness and safety of vaccines is an important strategy to promote vaccination uptake and minimize the negative public effects of campaigns created by antivaccination groups.

VH is a complex global phenomenon. WHO considered VH as one of the top-ten global health threats [12]. According to WHO, VH threatens to reverse the historic global efforts to stop vaccine-preventable diseases. VH is a continuum between full acceptance and complete refusal [13]. WHO hypothesized that three main factors contribute to VH: lack of confidence, perception of no need for the vaccine, and difficulty in accessing the vaccine [14].

The global pandemic of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), known as coronavirus disease 2019 (COVID-19), has killed millions of people worldwide. Due to the absence of an effective, safe, and quick pharmacological approach to treating COVID-19 patients, an effective vaccine is considered critical to ending the COVID-2019 pandemic. In March 2020, the journey to develop a safe and effective vaccine against COVID-19 was started by global pharmaceutical companies [15, 16]. In December 2020, the US Food and Drug Administration (FDA) approved the first COVID-19 vaccine based on safety and efficacy data provided by pharmaceutical companies [17]. The introduction of the COVID-19 vaccine was a turning point and a key global public health success.

The development and authorization of the COVID-19 vaccine were made within 12 months of the start of the pandemic in China. This is in contrast to the regular process of developing and authorizing vaccines for an infectious disease. This rapid authorization was made under the umbrella of "Emergency Use Authorization (EUA)" [17]. EUA was based on strong evidence of safety and efficacy ad high manufacturing quality data received by FDA and continuous post-marketing safety reports [18, 19]. Currently, approved COVID-19 vaccines use different technologies including mRNA vaccines and adenovirus vector-based vaccines [20]. These have been tested

Table 1. Research strategy for COVID-19 vaccine hesitancy for the period from 1 January 2021 to 31 December 2022

Step	Strategy	Keywords used	Result
1	Title search for COVID-19 related keywords	"covid-19" or "covid*" or "novel coronavirus" or "2019 novel coronavirus" or "coronavirus 2019" or "coronavirus disease 2019" or "2019-novel cov" or "2019 ncov" or "covid 2019" or "covid19" or "corona virus 2019" or "ncov-2019" or "ncov2019" or "ncov 2019" or "ncov" or "covid-19" or "severe acute respiratory syndrome coronavirus 2" or "sars-cov-2" or "corona virus" or (pandemic and corona*)	343,743
2	Title search for vaccine-related keywords	Vaccine or vaccination or immunization	262.815
3	Title-abstract search for the exact phrase "vaccine hesitancy"	"vaccin* hesitancy"	4,304
4	Title search for keywords related to vaccine hesitancy	("vaccin* reject*" or "vaccin* intent*" or "vaccin* refusal" or "vaccin* opposition" or "antivaccination group*" or "antivaxx group*" or "willingness to vaccinate" or "vaccin* accept*" or "vaccin* resist*" or "vaccin* uptake" or "vaccin* conspiracy" or "vaccin* misinformation" or "vaccin* skepticism" or "accept* of the vaccin*" or "intent* to vaccin*" or "intent* to get vaccin*" or "accept* of covid* vaccin*" or "accept* of a" or "mandatory vaccin*" or "compulsory vaccin*" or "attitude* toward* vaccin*" or "attitude toward* covid-19 vaccin*" or "accept* covid-19 vaccin*" or (attitude* and toward* and vaccin*) or (vaccin* and program* and challenge*) or (vaccin* and reject*)	6,439
5	Steps 1 & 2 & (3 or 4)		3,511
6	Limitations on step 5	The period from 1 January 2021 to 31 December 2022: Journal research & review articles	2,934
7	Exclusion	Articles on influenza vaccine during COVID-pandemic or articles on access & affordability of vaccine	2,886
Net result			**2,886**

for safety and efficacy several years before the appearance of the COVID-19 pandemic [21]. Despite the safety profile and history of proven efficacy of the novel vaccine technologies, the acceptance rates of COVID-19 vaccines in the general population were less than optimal constituting a threat to global efforts to eliminate the pandemic [22, 23]. Several published studies pointed out the dangers of VH in the efforts to combat the COVID-19 pandemic [24, 25].

Several editorials, research articles, and reviews were published about COVID-19 VH [15, 26, 27]. However, due to the importance of COVID-19 VH, as a threat to global health security, the current study was undertaken to investigate the volume, geographical origin, research pattern, scientific disciplines involved in the emergence of this topic, and map the published literature for easy understanding and identification of hot spots in the field. The current study adds to the literature on COVID-19 VH as an individual effort to overcome VH. Analysis of existing literature on COVID-19 VH provides information regarding the ongoing global and national efforts to identify factors responsible for the potential failure of COVID-19 vaccination programs in certain countries or among certain ethnic or religious groups. Analysis and mapping of literature on a certain topic are carried out using bibliometric analysis defined as the application of mathematical and statistical analysis on a dataset retrieved from scientific databases. In addition to mathematical and statistical analysis, bibliometric analysis is used to construct a visualization network for research collaboration, co-occurrence of author keywords, and citation/co-citation of the most important journals involved in publishing documents on the topic.

MATERIALS AND METHODS

The current study used Scopus database because it has:

(1) more than 23 thousand indexed journals in various scientific disciplines,

(2) analytic functions that allow for data analysis, and

(3) functions that allow for the export of data to Microsoft Excel and other programs such as VOSviewer used for mapping.

The overall search strategy was presented in **Table 1**. Keywords related to the vaccine were used in the title search and included vaccine, vaccination, and immunization. Keywords related to COVID-19 were also used in the title search and included 18 keywords related to COVID-19. Keywords related to VH included 26 keywords. There are many keywords in scientific literature that indicate VH and that is why a large number of keywords were used. For example, the keywords "refusal", "opposition", "delay", "antivaccination", "antivax", "acceptance", "reluctance", "uptake", "willingness", "resistant", "resistance", "intention", skeptics/skepticism about vaccine*, "doubts about vaccine*", "mistrust", "lack of confidence", and others were found in VH literature. The use of this relatively high number of keywords will ensure the comprehensiveness of the investigation. Truncated keywords were used with the asterisk to retrieve all possible combinations while quotation marks were used to retrieve the exact phrase. The use of a single database in the investigation is justified since 100% of articles in PubMed are included in Scopus and more than 95% of journals indexed in Web of Science are also indexed in Scopus [28-30].

The results were filtered by limiting documents to journal research articles or reviews while editorials, notes, letters, books, and book chapters were excluded. The results were also limited to the period from January 01, 2021, to December 31, 2022, since the administration of COVID-19 vaccine took place in the past two years. Therefore, articles published on VH in the context of COVID-19 during the year 2020 were excluded. Data extraction and analysis was carried out on February 04, 2023.

Validation

To validate the strategy, the author asked two volunteers in the medical field to review the titles and abstracts of the top-50 cited documents to make sure that none was irrelevant or outside the scope of the topic. Based on the review process, articles with the following words in the title were excluded ("influenza vaccination", "influenza vaccine", and access to vaccin*). No false-positive results were found after the exclusion step.

Table 2. Top-10 subject areas of articles on COVID-19 vaccine hesitancy for period from 1 January 2021 to 31 December 2022

Subject area	n	P (%) (N)
Medicine	2,338	81.0
Immunology & microbiology	798	27.7
Pharmacology, toxicology, & pharmaceutics	633	21.9
Social sciences	313	10.8
Biochemistry, genetics, & molecular biology	232	8.0
Multidisciplinary	161	5.6
Psychology	158	5.5
Veterinary	142	4.9
Nursing	115	4.0
Environmental science	109	3.8

Note. n: Number of publications; P: Percentage; & N=2,886

Data Export and Bibliometric Indicators

The refined results were exported to Microsoft Excel and the following results were generated:

1. Growth pattern and subject areas of the retrieved articles.
2. Core countries, institutions, journals and authors in publishing the retrieved articles.
3. Map of author keyword co-occurrence to identify hot topics and map of frequent terms in titles and abstracts to identify research themes.
4. Map of co-citation analysis to identify disciplines involved in the emergence of the COVID-19 VH.
5. Map of international research collaboration.
6. Top 10 cited articles.

The bibliometric maps were generated using the free online program VOSviewer [31]. In VOSviewer maps, items are presented as nodes. The larger the size of the node the higher the frequency of occurrence of the item. The distance between two items on the map indicates relatedness. Closer items are strongly related, and the opposite is true for distantly located items. In the cross-country (international) research collaboration visualization map, the extent of international research collaboration is measured by total link strength (TLS), which is given by VOSviewer program based on the number of links between each country with other countries.

Statistical Analysis

Correlation between number of publications produced by core countries and income, measured by the World Bank 2020 gross domestic product (GDP) per capita, COVID-19 vaccine acceptance rate, and the extent of international collaboration was measured using the Spearman correlation test in SPSS (statistical package for social sciences) (Armonk, NY: IBM Corp).

RESULTS

Characteristics of the Retrieved Articles

During the specified study period, 2886 articles related to VH were published in peer-reviewed scientific journals. Of these, 187 (6.5%) were review articles while remaining 2,699 (93.5%) were research articles. About 87.2% of retrieved articles (n=2,518) were available in open access sources.

Languages of the Retrieved Articles

Scopus database indicated that the retrieved articles were published in 16 different languages, mainly English (n=2838, 98.3%). The remaining 48 (1.7%) articles were written in non-English but have bilingual abstracts (English and non-English). The presence of bilingual abstracts is a condition imposed by Scopus on all non-English journals that are indexed in the Scopus database. The most common non-English language was Spanish, German, and Chinese.

Subject Areas of the Retrieved Articles

The Scopus database has categorized the retrieved articles into 26 subject areas. Because certain journals may be categorized in more than one field, there was an overlap between the subject areas.

Table 2 presents top-10 subject areas of retrieved articles. Subject area of "medicine" has highest number of publications (n=2,338, 81.0%), followed by immunology/microbiology (n=798, 27.7%) and pharmacology (n=633, 21.9%).

Growth of Articles

Of the retrieved articles, 961 (33.3%) were published in 2021, and 11925 (66.7%) were published in the year of 2022.

Spatial Distribution of Publications and Their Collaboration Networks

The retrieved articles were published by authors from 138 different countries/territories, more than 70% of the member states (n=195) in the United Nations. The country with the most publications was the United States (US) (n=1,011, 33.0%), followed by the United Kingdom (UK) (n=308, 10.7%), and China (n=223, 7.7%).

Table 3 lists the core countries (n=27) with a minimum contribution of 40 articles each.

Table 3. Core countries publishing at least 10 articles on COVID-19 vaccine hesitancy for period from 1 January 2021 to 31 December 2022

Country	n	P (%) (N)	#GDP (*103) [34]	AR (%) [35]	TLS*	CPA
United States	1,011	35.0	63.4	66	564	14.3
United Kingdom	308	10.7	41.1	81	393	27.0
China	223	7.7	10.4	82	191	8.8
Italy	167	5.8	31.7	82	127	13.7
India	140	4.9	1.9	79	193	9.5
Canada	131	4.5	42.3	91	128	13.0
Australia	115	4.0	51.7	59	158	11.4
Germany	98	3.4	46.2	60	134	12.2
Saudi Arabia	84	2.9	20.1	69	160	10.2
Turkey	81	2.8	8.5	66	112	13.1
France	76	2.6	39.0	47	95	22.5

Table 3 (Continued). Core countries publishing at least 10 articles on COVID-19 vaccine hesitancy for period from 1 January 2021 to 31 December 2022

Country	n	P (%) (N)	GDPPC (*103) [34]	AR (%) [35]	TLS*	CPA
France	76	2.6	39.0	47	95	22.5
Hong Kong	74	2.6	46.3	42	107	8.6
Pakistan	70	2.4	1.2	72	184	15.5
Malaysia	68	2.4	10.4	83	159	11.8
South Africa	62	2.1	5.1	76	100	9.6
Ethiopia	57	2.0	0.9	92	22	9.0
Japan	54	1.9	40.2	56	60	14.2
Bangladesh	51	1.8	2.0	61	129	22.1
Nigeria	51	1.8	2.1	76	116	13.0
Poland	49	1.7	15.7	51	55	13.2
Egypt	47	1.6	3.5	28	140	11.8
Spain	46	1.6	27.1	48	79	35.9
United Arab Emirates	46	1.6	36.3	60	113	11.0
Jordan	44	1.5	4.3	25	60	48.2
Belgium	43	1.5	45.2	73	71	42.2
Indonesia	40	1.4	4.3	65	92	6.5
Israel	40	1.4	52.2	75	38	9.1

Note. n: Number of publications; P: Percentage; N=2,886; GDPPC: Gross domestic product per capita; AR: COVID-19 vaccine acceptance rate; CPA: Citations per article; & *TLS: Total link strength obtained from VOSviewer program & is used as a measure of strength of collaboration

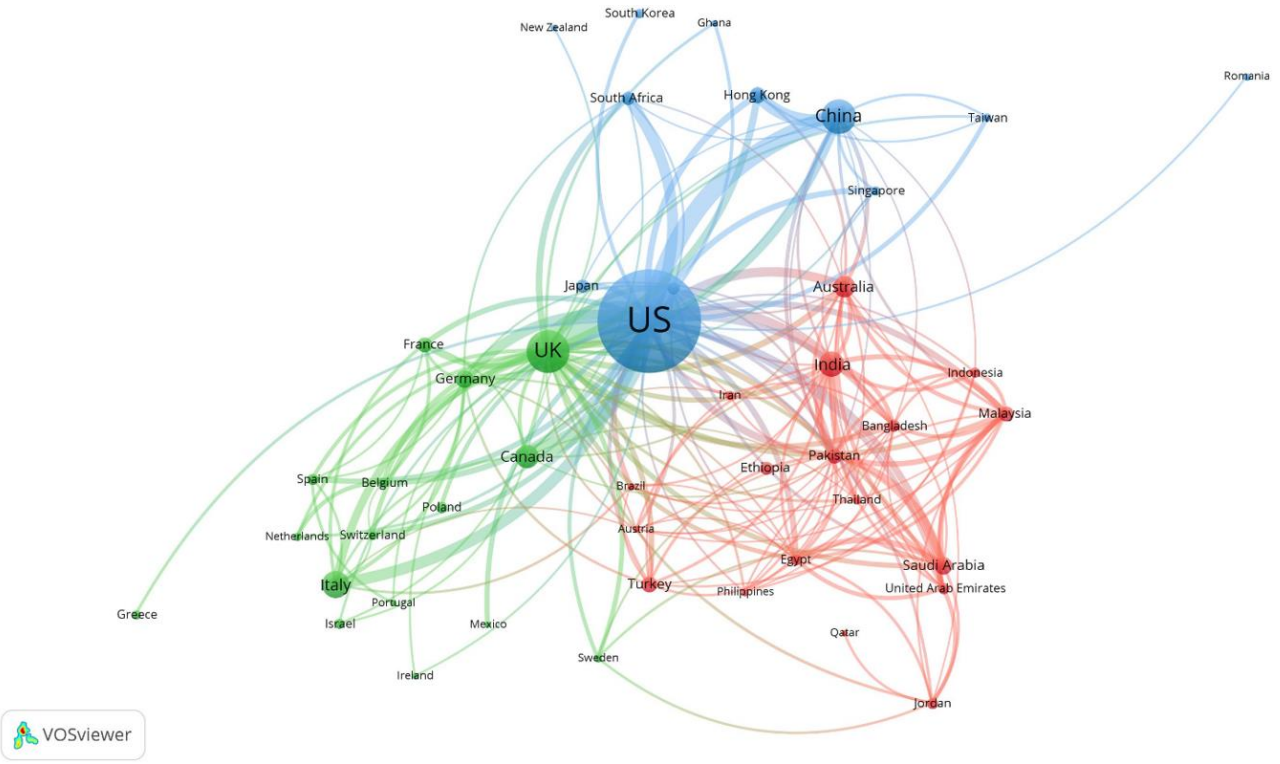

Figure 1. Network visualization map of international research collaboration on COVID-19 vaccine hesitancy among countries with a minimum contribution of 20 articles (period of the study was from 1 January 2021 to 31 December 2022) (Source: Author's own elaboration, using VOSviewer software)

The core list included countries from different world regions including the Eastern Mediterranean and African Regions. No significant correlation was found between the number of publications and COVID-19 vaccine acceptance rate (p=0.145). However, there was a significant correlation between the number of publications and the extent of international research collaboration, as measured by TLS (p<0.01, r=0.9), and income, measured by GDP (nominal) per capita (p=0.028, r=0.424).

Figure 1 shows the network visualization map of international research collaboration among countries with a minimum contribution of 20 articles each (n=45).

The extent of international research collaboration, measured by total link strength (TLS), was highest for the US (TLS=564), followed by the UK (TLS=393), and India (TLS=193). The thickness of the connecting line between countries represents the strength of research collaboration. Relatively, the US/UK had the thickest connecting line, followed by the US/China indicative of strong research collaboration.

Table 4. Core institutions/organizations (top-10) publishing articles on COVID-19 vaccine hesitancy for period from 1 January 2021 to 31 December 2022

Rank*	Institutions/organization	n	P (%) (N)	NPCA	CA
1	Harvard University	77	2.7	23.3	US
2	Johns Hopkins University	38	1.3	23.7	US
2	University College London	38	1.3	41.7	UK
4	London School of Hygiene & Tropical Medicine	36	1.2	64.9	UK
5	University of Oxford	34	1.2	24.7	UK
6	University of Toronto	31	1.1	14.3	Canada
7	Chinese University of Hong Kong	29	1.0	8.6	China
8	Inserm	29	1.0	36.3	France
9	University of California, Los Angeles	28	1.0	12.2	US
10	University of Pennsylvania	26	0.9	15.0	US
10	University of Michigan, Ann Arbor	26	0.9	26.9	US

Note. *In ranking system, two equal institutions were given same rank & one position is skipped; n: Number of publications; P: Percentage; N=2,886; NCPA: Number of citations per article; & CA: Country affiliation

Table 5. Core journals publishing at least 20 articles on COVID-19 vaccine hesitancy for period from 1 January 2021 to 31 December 2022

Journal name	n	P (%) (N)	NCPA	CiteScore	Publisher
Vaccines	410	14.2	18.6	4.5	MDPI
Human Vaccines & Immunotherapeutics	130	4.5	11.2	5.5	Taylor & Francis
Plos ONE	119	4.1	16.2	5.6	Public Library of Science
Vaccine	119	4.1	12.2	6.7	Elsevier
Frontiers in Public Health	94	3.3	9.1	4.0	Frontiers Media S. A.
International Journal of Environmental Research & Public Health	92	3.2	9.3	4.5	MDPI
BMC Public Health	44	1.5	11.9	4.9	Springer Nature
BMJ Open	40	1.4	5.4	3.9	BMJ Publishing Group
Scientific Reports	23	0.8	7.7	6.9	Springer Nature
Frontiers in Medicine	20	0.7	12.4	3.4	Frontiers Media S. A.
Frontiers in Psychology	20	0.7	4.0	4.0	Frontiers Media S. A.
Journal of Community Health	20	0.7	40.8	4.7	Springer Nature
Social Science & Medicine	20	0.7	20.3	6.9	Elsevier

Note. n: Number of publications; P: Percentage; N=2,886; & NCPA: Number of citations per article

Table 4 lists top-10 active institutions/organizations on VH. Harvard University (n=77, 2.7%) ranked first. The Johns Hopkins University and the University College London ranked second with 38 (1.3%) publications for each. The top active institutions included five from the US, three from the UK, one from France, one from China, and one from Canada.

Core Journals

Retrieved articles were disseminated through 795 scientific journals. 13 journals contributed at least 20 articles each (**Table 5**). The core journals published 1,151 (39.9%) articles. *Vaccines* journal (publisher: Multidisciplinary Digital Publishing Institute [MDPI]) ranked first with 410 (14.2%) articles, followed by *Human Vaccines and Immunotherapeutics* journal (publisher: Taylor & Francis) (n=130, 4.5%). Articles published in *Journal of Community Health* received the highest number of citations per article (n=40.8), followed by those published in *Social Science and Medicine Journal* (n=20.3) Journals indexed in SciVerse Scopus receive an annual "CiteScore", which is the average number of citations for the articles published in each journal and is used as a comparative measure of strength in general. Five journals in the core list have a CiteScore ≥5.0.

To examine the scientific disciplines underlying research on VH, a journal co-citation analysis was performed. Co-citation refers to the situation when two papers are cited together by a different paper [32]. In this analysis, only journals with at least 100 citations were considered (n=96). Resultant network visualization mapping is shown in **Figure 2**.

Circles with the largest size represent journals (disciplines) that played a key role in the emergence of the field. Microbiology/immunology/vaccinology was most influential discipline as represented by *vaccine* and *vaccines* journals. Less influential disciplines included general medicine (*Lancet*, *BMJ*, & *JAMA*) and multidisciplinary fields (e.g., *Plos ONE*).

Citation Analysis and Highly Cited Articles

The retrieved articles received 37,457 citations, an average of 13.0 (95% confidence interval [CI]: 11.2-14.4) citations per article. The median number of citations was 3.0 (interquartile range=10). The h-index of the retrieved articles was 81.

Table 6 shows the top-10 cited articles in the field of VH. The range of citations received by the top-10 cited articles was from 340-1,232. Three articles in the list were review articles and seven were research articles. All top-cited articles were published in 2021. The top-10 cited articles were published in journals in diverse medical fields including internal medicine, public health, epidemiology, and immunology/microbiology.

Authorship Analysis

Table 7 is a list of top-10 active authors. appeared to be the most productive authors with 12 (0.4%) articles. Khubchandani J, from the US, was the author of the most cited articles in this field. He has published nine articles with an average of 93.2 citations per article. The average number of citations of articles published by core authors was approximately 28.7 citations per article. More than half of the top active authors were based in the US.

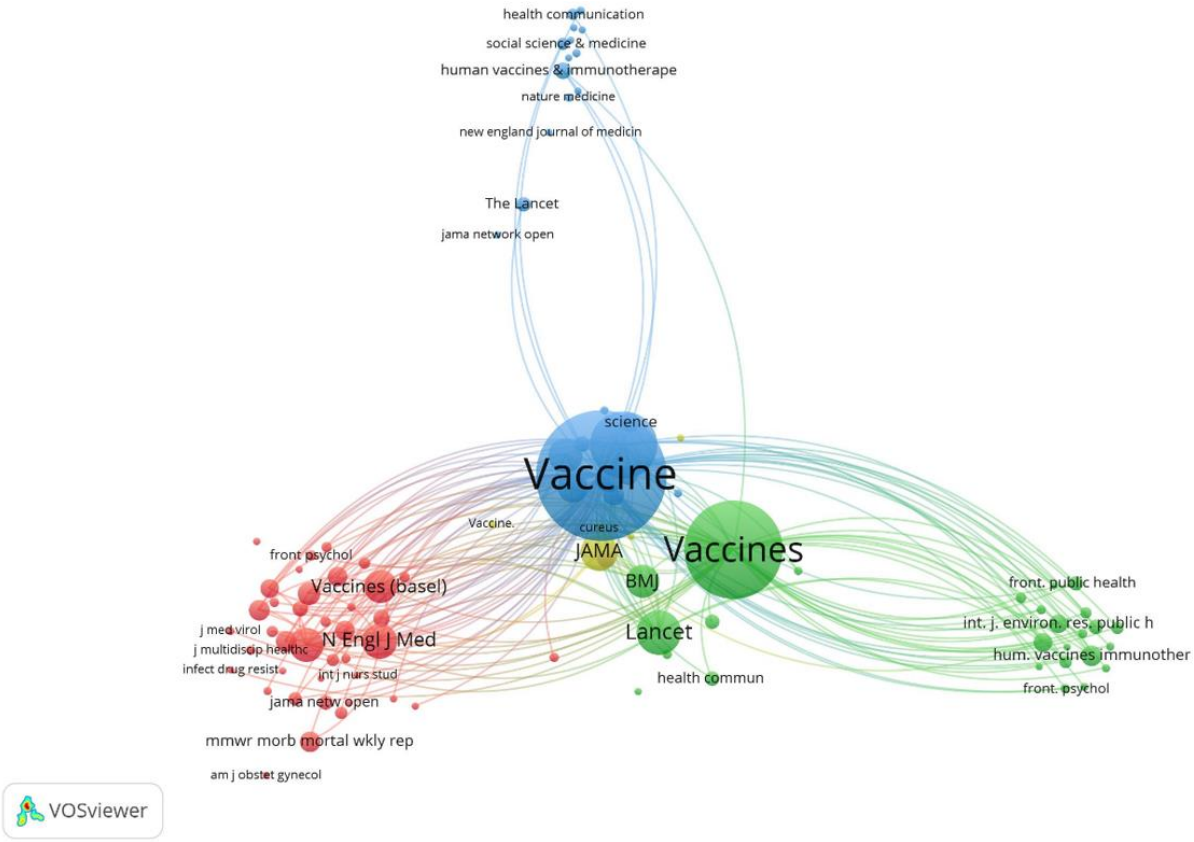

Figure 2. Co-citation analysis of journals with minimum of 50 citations & publishing articles on COVID-19 vaccine hesitancy (large nodes represent journals that helped in emergence of COVID-19 vaccine hesitancy as a research topic & period of study was from 1 January 2021 to 31 December 2022) (Source: Author's own elaboration, using VOSviewer software)

Table 6. Top-10 cited articles on COVID-19 vaccine hesitancy for period from 1 January 2021 to 31 December 2022

Rank	Title	Year	Source title	CB	NCPY
1	"A global survey of potential acceptance of a COVID-19 vaccine" [23]	2021	Nature Medicine	1,232	616.0
2	"COCID-19 vaccine hesitancy worldwide: A concise systematic review of vaccine acceptance rates" [27]	2021	Vaccines	804	402.0
3	"Psychological characteristics associated with COVID-19 vaccine hesitancy and resistance in Ireland and the United Kingdom" [36]	2021	Nature Communications	563	281.5
4	"COVID-19 vaccination hesitancy in the United States: A rapid national assessment" [37]	2021	Journal of Community Health	481	240.5
5	"Confidence and receptivity for COVID-19 vaccines: A rapid systematic review" [38]	2021	Vaccines	375	187.5
6	"Measuring the impact of COVID-19 vaccine misinformation on vaccination intent in the UK and USA" [39]	2021	Nature Human Behavior	514	257.0
7	"Attitudes towards vaccines and intention to vaccinate against COVID-19: Implications for public health communications" [40]	2021	Lancet Regional Health-Europe	424	212.0
8	"COVID-19 vaccine hesitancy in a representative working-age population in France: A survey experiment based on vaccine characteristics" [41]	2021	Lancet Public Health	371	185.5
9	"COVID-19 vaccine acceptance and hesitancy in low- and middle-income countries" [42]	2021	Nature Medicine	355	177.5
10	"Vaccine hesitancy in the era of COVID-19" [43]	2021	Public Health	340	170.0

Note. CB: Cited by & NCPY: Number of citations per year

Table 7. Top-10 authors publishing articles on COVID-19 vaccine hesitancy for period from 1 Januar 2021 to 31 December 2022

Author name	Number of publications	Percentage (%) (N=2,886)	Number of citations per article	Country affiliation
McElfish PA	12	0.4	16.8	US
Willis DE	11	0.4	18.4	US
Gori D	10	0.3	24.8	Italy
MacDonald SE	10	0.3	18.6	Canada
Piltch-Loeb R	10	0.3	18.5	US
Freeman D	9	0.3	48.4	UK
Khubchandani J	9	0.3	93.2	US
Liu J	9	0.3	15.9	China
Montalti M	9	0.3	26.4	Italy
Savoia E	9	0.3	27.6	US
Wagner AL	9	0.3	12.1	US

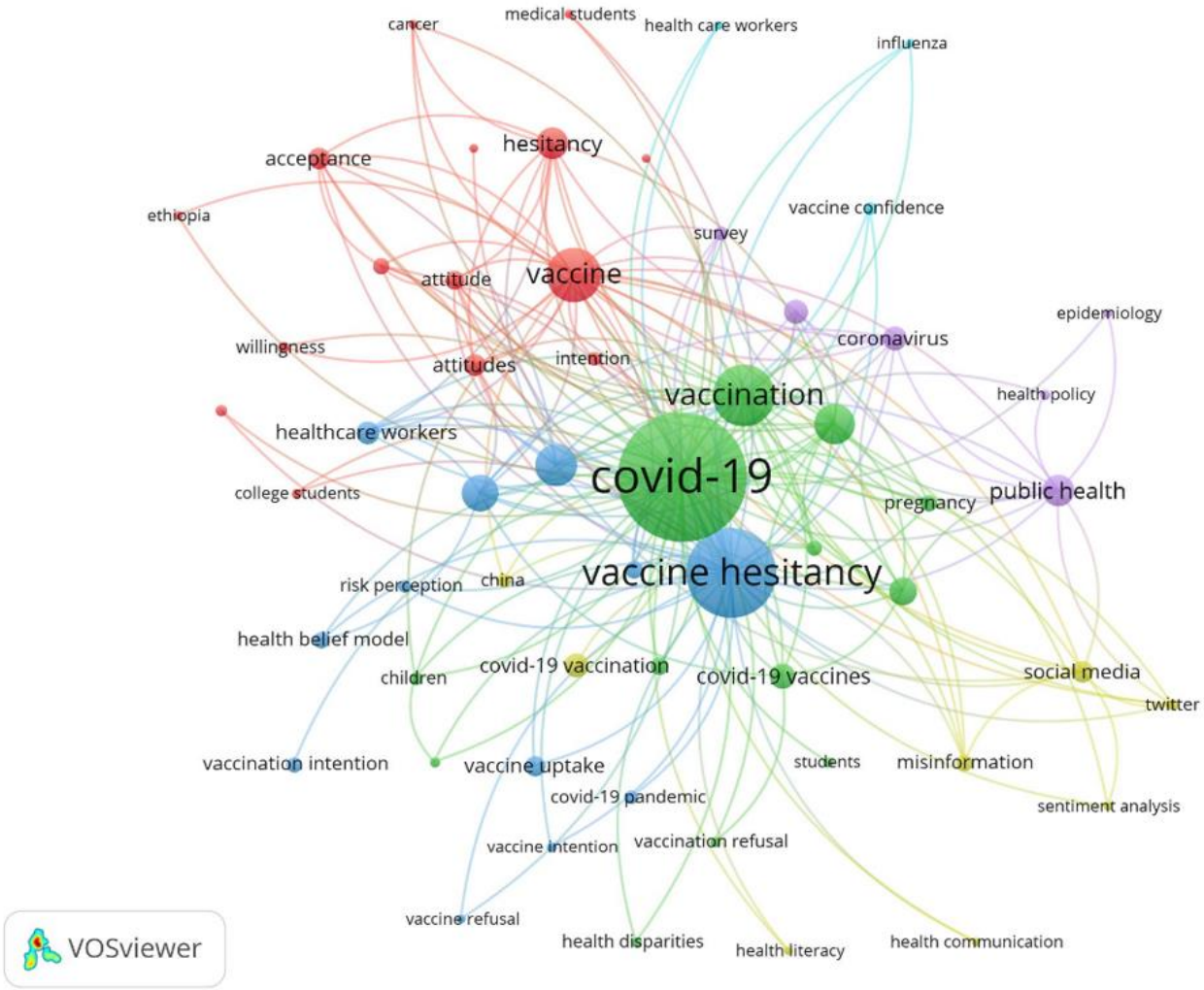

Figure 3. Network visualization map of author keywords with a minimum occurrence of 10 times in retrieved articles on COVID-19 vaccine hesitancy (period of study was from 1 January 2021 to 31 December 2022) (Source: Author's own elaboration, using VOSviewer software)

Keyword Co-Occurrence Analysis

Keyword co-occurrence analysis was carried out to identify hotspots in the dataset. The size of the node in the visualization map indicates the number of times the keyword appears while the nodes' color represents keyword clusters, which can be interpreted as broad research topics in the field [33]. In the current analysis, only keywords with a minimum of 20 occurrences were included. Therefore, of all keywords, 57 met the minimum threshold and were mapped. The keyword "COVID-19" has the highest occurrences (n=1,610), followed by the keyword "vaccine hesitancy" (n=884) (**Figure 3**).

Mapping Frequent Terms in Titles and Abstracts of the Retrieved Data

Figure 4 is a density visualization of terms in the titles/abstracts with a minimum occurrence of 20 times.

Items with large font size represents a research cluster. The largest clusters represented research that focused on misinformation and its impact on vaccination intention and the second-largest cluster focused on questionnaire-based cross-sectional studies on VH among healthcare workers (HCWs) and medical students.

Funding of Research Publications

The data revealed that 1,093 (37.9%) of the research articles were financially sponsored by various sponsors. Among these funding agencies, *National Institutes of Health* (the US) (n=134, 4.6%) and *National Natural Science Foundation of China* (n=53, 1.8%) were the most active.

DISCUSSION

The current study came as part of the global efforts to eliminate one of the obstacles in vaccination programs for COVID-19, specifically VH. Research on VH leads to development of interventional strategies that can increase vaccine acceptance [44, 45]. The current study analyzed research trends and patterns on VH to give an overview of the current research efforts, recommend future policies, and give credit to those who made the most efforts to combat VH. The analysis was limited to scientific output published in the past two years, from January 01, 2021, to December 31, 2022. The findings of the current study indicated that the number of publications on COVID-19 VH was doubled during the study period, which is higher than the average increase in global scientific research that was estimated to double every nine

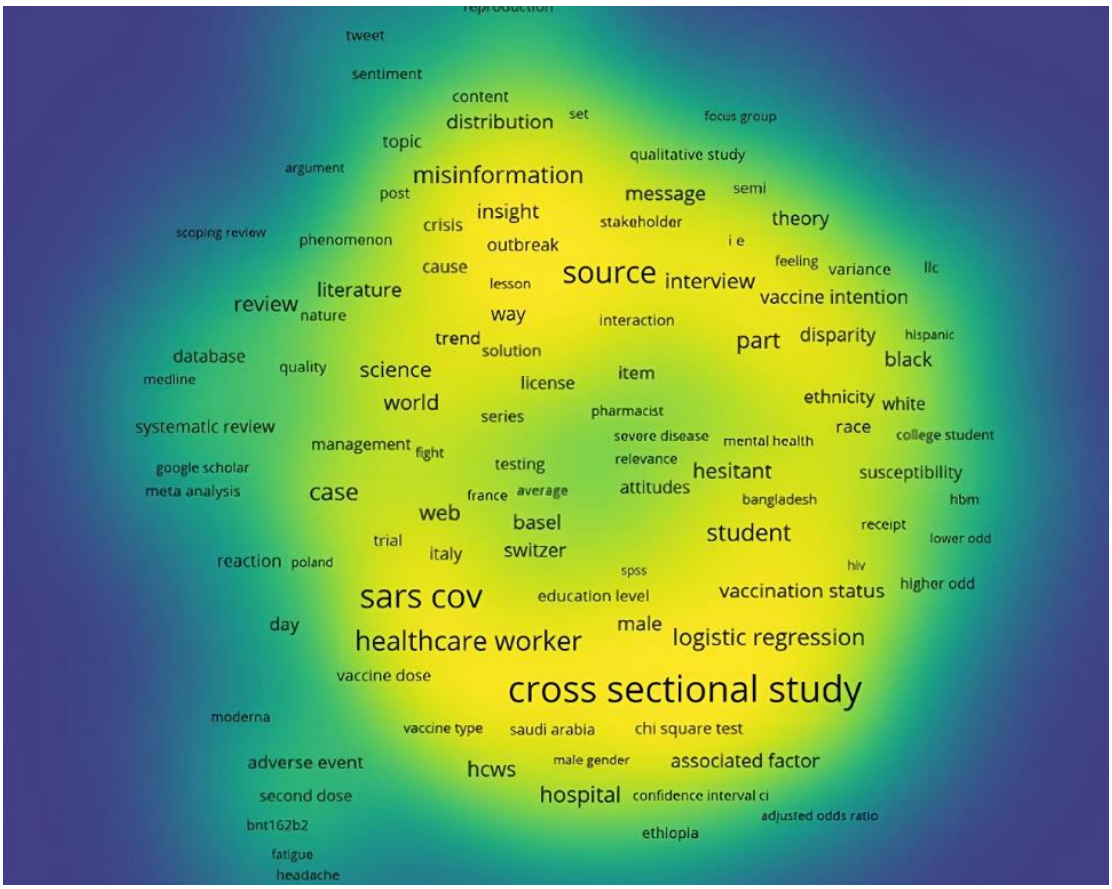

Figure 4. Density visualization map of most frequent terms in titles/abstracts of retrieved articles on COVID-19 vaccine hesitancy (a minimum threshold of 10 occurrences was used & period of study was from 1 January 2021 to 31 December 2022) (Source: Author's own elaboration, using VOSviewer software)

years [46]. This might be due to the reported low rates of vaccine acceptance and the serious economic and health consequences of VH [35, 47-49].

The results in the current study indicated that there was approximately 5.5% of the publications in the subject area of psychology. Identifying and understanding the psychological basis of COVID-19 VH help future public health policy planning [36]. Studies indicated that people with personal beliefs against vaccines had lower acceptance than those who received the vaccinations. Furthermore, religious people and women tend to have lower acceptance of the vaccine [43]. A study found a positive correlation between the belief in conspiracy theories and VH [50]. The study also found that people who do not feel afraid of COVID-19 would hesitate about vaccination. Therefore, developing and implementing educational methods to spread accurate information about the safety and effectiveness of COVID-19 vaccine is important for eliminating VH. A study showed that education intervention was effective in reducing COVID-19 VH among individuals who were unreceptive of the vaccine [51]. This education should be directed to children and adolescents using different means to eliminate VH in the next generation [52].

The current study indicated that approximately one-third of the retrieved articles were published by US scholars and half of the top-ten active institutions and authors were based in the US. This is in accordance with the results obtained in many bibliometric studies on other health and social topics [53-55]. Traditionally, VH is a problem in high-income countries because the anti-vaccination groups started in high-income countries [48, 56]. Furthermore, the false research claim linking vaccination to autism started in high-income countries [57, 58]. It has been reported that VH affects countries and regions in high-income countries more than in low- and middle-income countries [59]. Despite this, the findings in the current study showed that articles published by scholars in Jordan received the highest number of citations per article. One of the review articles published by a Jordanian author received relatively a high number of citations and was one of the top-cited articles in the field [27]. Furthermore, scholars from Jordan published epidemiologic data on the exceptionally low rate of vaccine acceptance among Jordanian and Arabs [60]. There are several factors that could affect the volume of research output on any field. Financial support, research collaboration, infrastructure and scientific resources, and the number of scholars in the field are also key factors in determining the volume of research output [61, 62]. The availability of these key factors is one potential reason for the large research output of scholars from the US. The list of core countries included both the United Arab Emirates and Saudi Arabia since fighting the pandemic and VH is essential for these countries to maintain international trade and religious tourism in these countries [63-65].

The current study indicated that journals outside the field of immunology/microbiology have made a good contribution and helped in the emergence of the topic. Most of these journals were in the field of general medicine/public health such as the Lancet, JAMA, BMJ, Public Health journals, and others. Vaccination is considered one of the most important medical interventions to overcome vaccine-preventable infections and save lives and the economy [66]. Therefore, VH

is of a special public health concern, and several leading public health journals gave this topic a priority during the pandemic. Certain public health journals such as *International Journal of Environmental Research and Public Health* launched a special issue on VH under the section "infectious disease epidemiology". There was a small percentage of articles published in journals within the subject area of environmental sciences. This could be due to the fact that certain journals in the field of environmental sciences have a public health dimension.

The current study indicated that research on VH among HCW was an important research theme. HCWs have a higher risk of being affected by COVID-19 due to their working environment [67]. VH among HCW and medical students has a triple-negative effect, by affecting the workforce in the health system, exposing themselves to disease risk, and negatively affecting public opinion about vaccines. A study showed that when COVID-19 vaccines were introduced, approximately 29% of HCWs were not willing to get vaccinated comparable with 27% of the general public [68]. Therefore, focusing VH research on HCW was not surprising given previous reports of low uptake rates of vaccines among HCW [69]. A survey study on medical students indicated less than optimal response regarding willingness to vaccinate against COVID-19 [70]. The authors of the survey study suggested more awareness and education materials about vaccine safety among medical students. Another research theme was the spread of misinformation about the safety and effectiveness of COVID-19 vaccine. Most of the misinformation about COVID-19 was spread through the internet [66]. It is important that governments develop strategies to censor health information regarding serious public health crisis.[39, 71-74] One of the potential causes of this global fear of vaccination is the fast spread of fake news, misinformation, and conspiracy theory regarding the COVID-19 vaccine through various types of social media [75, 76]. A recently published article on VH, in general, indicated that the US and countries in the European Region were among the top 10 in the number of publications on VH in general [77]. However, in the current study, countries such as China, Saudi Arabia, and India were among the top 10 in the number of publications on COVID-19 VH. The difference cannot be attributed to a sudden scientific revolution. Rather, such a leading role is mainly attributed to governmental policies that encouraged vaccination as one important means to overcome the pandemic and return to economic growth [78].

The current study and the findings obtained should be translated into interventional and strategic plans to overcome VH in general. First, poor or low research contribution from any country or region does not mean that the uptake or acceptance rate of vaccination is high. Therefore, research studies on the topic are highly needed in every country and among all minority groups to direct efforts correctly. Second, HCWs are at the frontline in combating infectious disease outbreaks. Therefore, the educational curricula for medical and non-medical students should include evidence-based materials regarding the safety, efficacy, and tolerability of vaccination in general [15, 79-82]. Third, collaborative efforts among researchers in different countries should be encouraged and funded. Fourth, medical journals need to launch call for papers on the special issue of VH to encourage researchers from different scientific disciplines to participate in the discussion about this topic. Fifth, special attention should be given to cultural and religious minorities and investigate their access to the COVID-19 vaccine to overcome VH [83-86]. Finally, research on VH should not be limited by a period. There must be a continuous effort through all communication means to disprove anti-vaccine groups' efforts.

Analysis of research on COVID-19 VH can help us determine the future direction of research in the field of VH. For potential future research, focusing on and monitoring the content of social media about misinformation and fake news about vaccines is a promising step in fighting the roots of VH [6, 87]. Artificial intelligence applications have been suggested as a tool for monitoring and detecting misinformation on social media about vaccination [88, 89]. Another important future research avenue is the role of HCW in VH. Campaigns about the safety and efficacy of vaccines among HCWs, nurses, and medical students are important to prepare HVWs for future pandemics. VH among HCWs negatively affects the public attitude toward vaccination and decreases the confidence of the public in health professionals [90]. Future research emphasis is also needed on the psychological components of VH among specific groups.

All bibliometric studies have inherent limitations related to the perfectness of the search strategy, citation analysis, active authors, and institutions. Therefore, the author acknowledges these limitations, which make the findings accurate within the context of the methodology used and the time of analysis.

CONCLUSIONS

As a conclusion, research analysis of global scientific publications on COVID-19 VH showed a steep rise in 2022. Despite that, the US contributed to approximately one-third of the literature on the topic, the contribution of other world regions, especially certain Arab Gulf countries was noticeable. The scientific literature on the topic was disseminated through leading journals in the field of immunology/microbiology and public health. To overcome factors behind VH, more research is needed to shed light on the role of HCWs, and misinformation spread through social media about COVID-19 vaccine.

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