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Occupational Exposure to Formaldehyde: Research Trends and Scientific Contributions

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Highlights:

- Occupational exposure
- Bibliometric analysis
- Risk assessment
- Formaldehyde exposure

Keywords:

- Formaldehyde
- Occupational exposure
- Occupational safety
- Bibliometric analysis

ABSTRACT:

Formaldehyde is a colorless, highly reactive volatile organic compound with a sharp odor, widely used in industrial production. Many workers are exposed to it in workplaces, leading to adverse health effects like asthma, dermatitis, and cancer. Prolonged exposure necessitates control measures and health monitoring. Bibliometric studies help understand scientific research's structure and development. This study investigated the scientific output on occupational exposure to formaldehyde using a data-driven analysis of publications obtained from Web of Science and Scopus. RStudio and VOSviewer were used for analysis, reviewing 2390 publications of 8011 authors in 3099 affiliations across 77 countries published between 1960 and 2024. The United States emerged as the most productive contributor. The analysis covered co-authorship, bibliographic coupling by countries, citation analysis, journal analysis, top authors, and term analysis. Key topics identified included occupational diseases caused by formaldehyde, air quality effects, toxicity, genotoxicity, risk analysis, and personal exposure assessments. The findings provide a broad overview of research trends and contributions in this field, highlighting areas relevant to health and safety.

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INTRODUCTION

Workers are routinely exposed to various chemical, physical, psychological, and ergonomic factors, which may cause some health issues. Even small amounts of Formaldehyde (FA) exposure can lead to occupational diseases in the workplace. As a volatile organic compound, FA is present in the environment and living organisms (Lipskerov et al. 2022). FA is indeed produced endogenously by humans (EFSA, 2014). It is the simplest member of the aldehydes with the formula HCHO. Because it is soluble in water, ethanol, and chloroform, FA is widely used in a water/methyl alcohol solution called formalin (Motta et al. 2021). FA is a colorless, flammable, and toxic gas with a pungent smell at room temperature (GangaReddy et al. 2022).

FA has been produced commercially since 1889 by the catalytic oxidation of methanol (Joshi et al. 2024). The global market demand stood at approximately 23 million tons per year. FA has many uses, mainly in the medical, agricultural, and chemical fields. In pathology laboratories, FA is used on tissue samples as a preservative agent. Thus, Cammalleri et al. state that professionals in pathology and gross anatomy laboratories are among those at higher risk of exposure to Formaldehyde, alongside workers in industrial production processes, industrial launderers, carpenters, veterinarians, breeders, embalmers, beauticians, printing-room workers and firefighters (Cammalleri et al. 2022). According to the International Agency for Research on Cancer (IARC) (2012), workers involved in the production of Formaldehyde and/or its solutions, the manufacturing of products containing FA or their use, and the combustion of products that release Formaldehyde may be exposed to high levels of Formaldehyde at elevated air concentrations (Cogliano et al. 2005). FA is widely found in domestic products such as construction materials, furniture, and cleaning products. This includes paints, coatings, insulation foams, glues, chipboards, MDF sheets, fabrics, carpets, household cleaners, deodorants, and pesticides. In addition, both active and secondhand smoking of tobacco or e-cigarettes releases FA during combustion (Cogliano et al. 2005, Salthammer et al. 2010). Therefore, workers can be exposed to FA not only in their workplaces but also in their homes.

FA primarily enters the body through respiration and ingestion and is poorly absorbed through the skin (Nishikawa et al. 2019; Lyapina 2012). Ingested in liquid form, FA can cause severe nausea, vomiting, diarrhea, and abdominal pain. FA is a known factor in the development of asthma and can suppress the central nervous system. In 1987, the EPA classified FA as a probable human carcinogen under unusually high or prolonged exposure conditions. Later, in 2006, the IARC classified FA as a Group I carcinogen, providing sufficient evidence of its role in nasopharyngeal carcinoma and leukemia (IARC 2006; USEPA 1986). Prolonged exposure to even low concentrations of FA may irritate the eyes and respiratory tract, cause skin sensitization, and asthma attacks. Acute symptoms of FA include coughing, heart palpitations, chest tightness, and burning sensations in the eyes and respiratory tract concentrations of 10 ppm. Higher concentrations can be fatal due to pulmonary edema and respiratory failure (Kriebel et al. 2001; Takahashi et al. 2007; Khoshakhlagh et al. 2023 Wakankar 2013).

Occupational exposure limits vary globally, influenced by a nation's legal framework and the standards set by national or international organizations. Therefore, the limited or permitted values of FA in the workplace vary among many organizations that establish occupational exposure standards for hazardous substances (Khoshakhlagh et al. 2023). In 2010, the World Health Organization (WHO) has suggested that exposure to FA should not exceed 100 μg/m³. The US Occupational Safety and Health Administration (OSHA) has established the maximum exposure limit (PEL) for FA at 922 $\mu g/m^3$. The National Institute of Occupational Safety and Health (NIOSH) has limited the permissible concentration of FA is 20 $\mu g/m^3$ in workplace air (Andrews and O'Connor 2020). The United States Environmental

Protection Agency (USEPA) has defined FA as Level 1 according to Acute Emergency Guideline Levels and occupational exposure (AEGL-1 (8-h)) is 1100 μg/m^3. The American Conference of Governmental Industrial Hygienists (ACGIH) has established the time-weighted average (TWA) concentration limit for FA exposure for most workers at 123 μg/m^3 during a standard 8-hour workday (Khoshakhlagh et al. 2023).

Bibliometrics is a technique that has been used since the 1890s (Badola and Agrawal 2023). As a scientific tool, bibliometric analysis is used to analyze publications in both a mathematical and statistical manner (Liu et al. 2022). Although it was not called bibliometry at the time, the oldest study on this subject dates to 1896 (Campbell 1896). Since this first example of bibliometric analysis, the method has frequently been applied to generate mathematical models on gathered statistical data of authors, publication year, citations, affiliations, keywords, publisher, etc. (Egghe and Rousseau 1990). In addition, this analysis may focus on specific publications such as journals, books, proceeding books, or reports.

To date, few studies have examined the bibliometric analysis of FA. In 2010, Zhang et al. studied a bibliometric analysis of SCI papers, including Volatile Organic Compounds (VOCs), between the years 1992 and 2007. Although FA is one of the three most important VOCs along with benzene and toluene, it ranks 15th among the top 20 most frequently used keywords. In the publication, which ranks Turkey 30th among the most productive countries, the importance of increasing foreign-language studies that contribute to international literature has been highlighted (Zhang et al. 2010). Liu et al. performed a meta-analysis on the health effects of FA only in civil buildings, studies published internationally between 1980 and 2017. Formaldehyde exposure in civil buildings is associated with asthma in adults and asthma in children, while the relationship between dermatitis or rhinitis was not significant (Liu et al. 2023). Another bibliometric study on pollutants was conducted by Pierpaoli and Ruello. They performed a bibliometric analysis using the Web of Science (WoS) database, covering the years 1990 to 2018. The study focused on indoor air quality (IAQ), specifically examining various pollutants including FA (Pierpaoli and Ruello 2018). Their study revealed a shift in IAQ research from a medical perspective to a focus on the characterization of pollutants. Compared to the publications mentioned, the main focus of our study is “occupational exposure to formaldehyde,” covering the broadest period from the first year the literature data (1960) were produced to the 2024. Its focus specifically on formaldehyde rather than on many chemicals sets it apart from other studies, taking into account comprehensive studies that include not only health effects but also the risk assessment-based technical papers.

In this study, the scientific output on occupational exposure to formaldehyde was systematically analyzed. With the comprehensive data obtained, it provided an opportunity to receive in-depth evaluation from a broader perspective. The topics that prominent figures and researchers working in this field focus on have been comprehensively presented.

MATERIALS AND METHODS

Data Collection

Bibliometric data have been gathered from two of the most widely referred repositories: Web of Science (WoS) and Scopus. The keyword that has been used for the search query ‘‘Occupational exposure to Formaldehyde’’ for both WoS and Scopus. Publications are filtered as articles, reviews, book chapters, short surveys, and data papers.

The data collected in WoS and Scopus contain important details in many different areas. Data such as publication year, authors, authors' addresses, title, abstract, source journal, subject categories, and references were analyzed among the publications, yielding outputs that served as the basis for this study.

Various types of data were collected and analyzed, including subject categories, related terms and output trends of publications, citation numbers, collaborations, and geographical and institutional distribution of authors and journals that publish research on the topic. Freely available software programs RStudio (www.rstudio.com) and VOSviewer (www.vosviewer.com) were used to analyze and visualize relationships between data. In this study, a search for "occupational exposure to formaldehyde" was conducted in both the WOS and Scopus databases. After removing duplicates from the combined documents, an analysis was performed on articles, reviews, book chapters, short surveys, and data papers published between 1960 and 2024. Documents such as notes, conference papers, meeting abstracts, letters, and editorials were excluded. WoS extracted 1086 documents, including 911 articles (87.8%), 122 reviews (11.8%), 4 book chapters (0.4%), and 1 data paper (0.1%). Scopus retrieved 2111 documents, consisting of 1780 articles (83.3%), 301 reviews (14.1%), 41 book chapters (1.9%), 15 short surveys (0.7%), and 1 data paper (0.05%). While comparing the results of these two databases for various publication growth queries, the information from both databases was merged using RStudio, and 2512 documents were reached. After DOI and author comparisons were made on an Excel Spreadsheet, duplicate data were removed, resulting in a final dataset of 2390 documents. These consisted of 2007 articles (84.0%), 330 reviews (13.8%), 37 book chapters (1.6%), 15 short surveys (0.6%), and 1 data paper (0.04%). To ensure that the findings were accurate and complete, three researchers evaluated them with verification.

RESULTS AND DISCUSSION

Performance of Publication

Publication outputs

The number of internationally accepted scientific studies, as well as their increasing trends, are important indicators of the importance researchers place on that subject. Thus, to obtain an overview of "occupational exposure to Formaldehyde" research, the annual number of articles since the early 1960s has been analyzed. During the first period (1961–1967), only three publications with three authors were identified, corresponding to an average of one author per publication. In the following periods, both publication counts, and author numbers increased steadily: 17 publications with 34 authors between 1968–1974 (2 authors per publication), 91 publications with 196 authors between 1975–1981 (2.2 per publication), and 203 publications with 677 authors between 1982–1988 (3.3 per publication). This upward trend continued, reaching 278 publications with 947 authors between 1989–1995, 334 publications with 1296 authors between 1996–2002, and 382 publications with 1746 authors between 2003–2009. A sharp rise was observed after 2010, with 517 publications and 3043 authors between 2010–2016 (5.9 per publication), and 565 publications with 3880 authors after 2017 (6.9 per publication). On average, there were 4.95 authors per publication across the entire study period. In studies published after 2010, it has been observed that the number of authors is above average compared to studies published before 1980. Over the study period, the number of publications about "occupational exposure to Formaldehyde" rose from 1 to 78, resulting in a total of 2390 publications.

It can be obtained that the publications have been written in 26 different languages. 86.1% of the publications have been published in English and 4.6% in German. Italian, Russian, and French languages vary between 1-2%, while the remaining 21 languages are below 1%.

Publication distribution of countries

The investigation into authors' countries relied on journal papers that provided the addresses and affiliations of at least one author. However, 923 articles from Scopus were excluded from this analysis due to the absence of author addresses. Based on the countries of the corresponding authors, 1403

(95.64%) of all publications with author address information were authored by individuals from a single country, while 64 (4.36%) were the result of international collaborations. Table 1 shows the top ten countries ranked by the total number of publications. The country that produces the most publications in the field of FA exposure is the USA, followed by France and Italy. It has been observed that the rate of international collaboration in publications is low, but the number of citations, which is a measure of the international impact of the publications, is high. Additionally, Sweden which has fewer publications compared to other countries, has the highest citation value per publication.

Table 1. Countries' performance in formaldehyde

Country	TP	SCP	MCP	TC	TC/TP
USA	370	353	17	13432	36.303
France	94	90	4	3655	38.883
Italy	94	91	3	1873	19.926
Germany	81	79	2	1731	21.370
China	80	77	3	2146	26.825
United Kingdom	46	44	2	1209	26.283
Sweden	45	45	0	2483	55.178
Canada	44	39	5	2078	47.227
Iran	39	33	6	325	8.333
Finland	39	38	1	1466	37.590

TP: total publications; SCP: single country publications; MCP: multiple country publications; TC: total citation; TC/TP: average of citation per publication

Figures 1A and 1B show the inter-country co-authorship relationship and the bibliographic collaboration relationship by country. Inter-country co-authorship appears in six clusters in Figure 1A, with the USA being the largest node. In Figure 1B, countries with at least five publications have been filtered; thus, 36 out of 77 countries have been included in the analysis. The USA, located at the center of five clusters with 35 connections, has strong ties with China, Italy, and France. Thus, the fact that the most frequently collaborated and bibliographically cooperative authors are found in the USA also indicates that it is the country with the highest number of international publications.

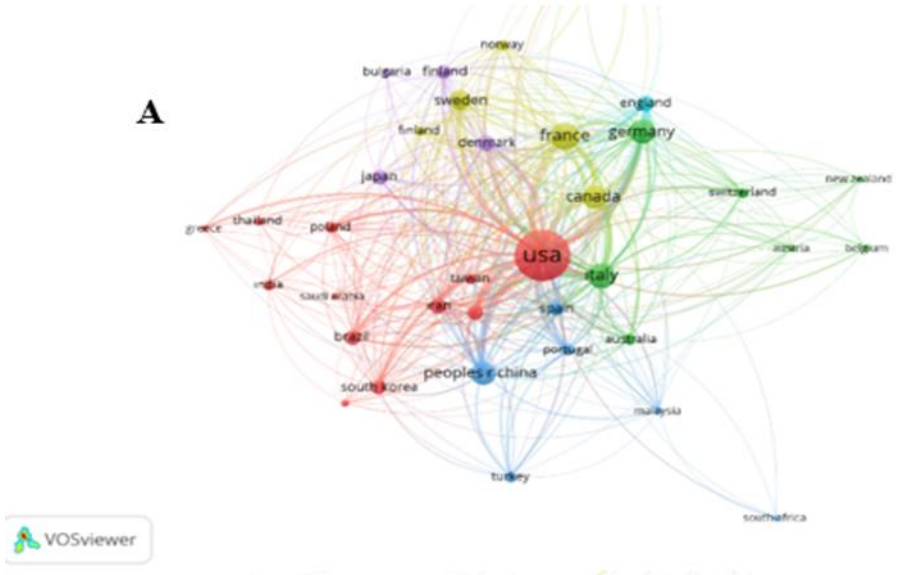

Figure 1. A) Co-authorship between countries. B) bibliographic coupling by countries. C) research output of affiliations over time. D) citation analysis among affiliations (minimum of five citations.)

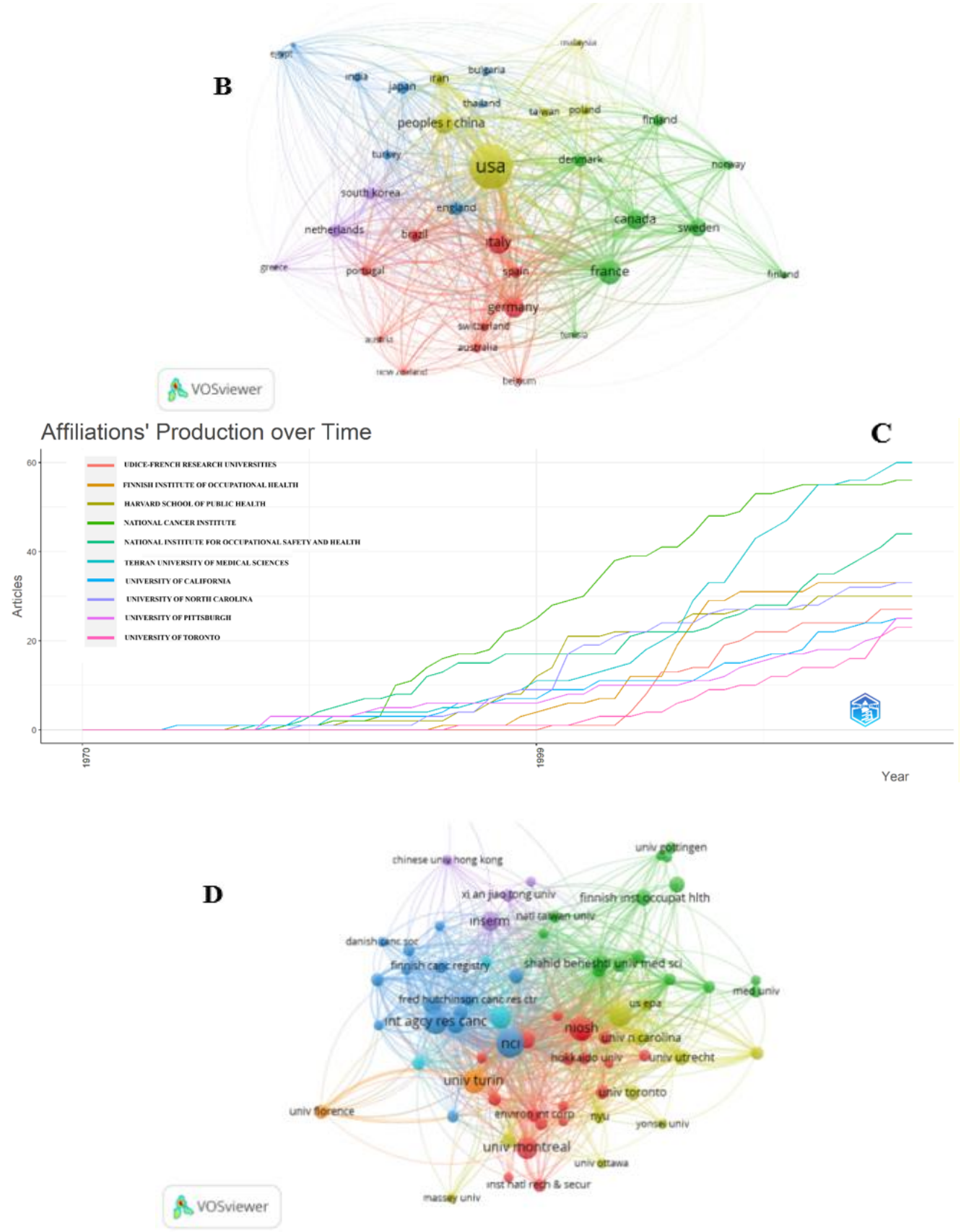

Figure 1. A) Co-authorship between countries. B) bibliographic coupling by countries. C) research output of affiliations over time. D) citation analysis among affiliations (minimum of five citations.)(Continued)

The ranking of the top 10 affiliations that have published the most research on "occupational exposure to Formaldehyde" is shown in Figure 1C. In terms of total publication count, the University of

California, the National Cancer Institute, and the National Institute for Occupational Safety and Health hold the top three positions. Six of these affiliations are based in the USA. Figure 1D shows the interactions between different institutions. It can be interpreted that the institutions found in the clusters shown in different colors are involved in similar research. Additionally, institutions with major nodes such as NIOSH, the National Cancer Institute, the University of Turin, or the Université de Montréal are observed to have high citation counts and to receive more citations than other institutions in the same clusters.

The United States is the country which has the most publications and cited studies. Moreover, most of the top 10 authors and top 10 journals publishing on this topic are from there. The factors contributing to these achievements may vary. FA production in the United States since the early years, and its use in various industries, may have led to more people being exposed and, consequently, more research being conducted. Furthermore, American institutions, such as OSHA, NIOSH and EPA establish strict occupational health and safety standards, conduct risk assessments and fund research on the topic due to FA being classified as carcinogen.

Top authors

A total of 2390 scientific studies on the topic of "occupational exposure to Formaldehyde" have been conducted by 8111 different authors. Approximately 80% of these authors (n = 6431/8111) have appeared in a single publication, 9% of them (n = 716/8111) have at least three publications on this topic, and the remaining 0.6% (n = 46/8111) of the minority have 10 or more publications.

Table 2 shows the 15 most productive authors publishing on the topic of "occupational exposure to Formaldehyde" since 1961. The ranking has been based on the total number of publications by the author, not the order of authors. Blair A. is the most productive author with 37 publications. He has been followed by Stewart P. with 33 publications and Boffetta P. with 26 publications. For the top 15 authors, the average number of citations per publication ranges from 98.28 to 28.46.

Table 2. Top authors working on formaldehyde

Author	Affiliation	Country	TP	TC	h	g	m	PY_start
Blair A.	National Cancer Institute	United States	37	2332	25	37	0.658	1986
Stewart P.	National Cancer Institute	United States	33	2606	23	33	0.605	1986
Boffetta P.	International Prevention Research Institute	France	26	1293	20	26	0.606	1991
Kauppinen T.	Finnish Institute of Occupational Health	Finland	20	805	17	20	0.436	1985
Geier J.	University of Gottingen	Germany	29	905	16	29	0.552	1995
Hayes R.	Erasmus University Rotterdam	Netherlands	18	1769	16	18	0.421	1986
Marsh G.	University of Pittsburgh	United States	25	777	16	25	0.381	1982
Zhang L.	University of California	United States	27	1882	16	27	0.762	2003
Jolanki R.	Finnish Institute of Occupational Health	Finland	13	578	13	13	0.419	1993
Smith M.	University of California	United States	18	1583	13	18	0.464	1996
Youk A.	University of Pittsburgh	United States	15	604	13	15	0.464	1996
Demers P.	University of British Columbia	Canada	14	951	12	14	0.414	1995
Kogevinas M.	University of Minnesota	France	12	771	12	12	0.364	1991
Dosemeci M.	National Cancer Institute	United States	12	754	11	12	0.324	1990
Pukkala E.	University of Tampere	Finland	13	370	11	13	0.289	1986

TP: total publications; TC: total citation; h: h-index; g: g-index; m: m-index; PY_start: publication year start

The average number of authors per publication is 4.95. 12.3% of the publications (n=293/2390) are single-authored, 15.6% (n=374/2390) are co-authored by two authors, 18.5% (n=441/2390) are co-authored by three authors, and 53.6% (n=1282/2390) are co-authored by four or more authors. Since multi-authored publications constitute more than half of all publications, it can be concluded that there is a significant amount of joint research on "occupational exposure to Formaldehyde." The number of

co-authored publications reflects a closer relationship among authors within the same field and highlights an increased potential for future collaborations.

The co-authorship analysis of authors with publications on the topic was conducted using VOSviewer. The more different authors cite the same publications in their works, the stronger their co-authorship relationship will be (Pierpaoli and Ruello 2018). The size of the nodes shown in Figure 2A represents the number of publications, and the distance between the two authors indicates their bibliographic collaboration inversely. In total, three major clusters can be mentioned. However, these sets are also in close relationships with each other which leads the authors in these clusters to have a high potential for citing the same publications. It appears that the main researchers in the network are Zhang, Boffetta, and Estlander. Figure 2B shows the co-authorship network that measures the degree of mutual publications between authors (Liu et al. 2023). The network represents the links among the authors working together. This analysis can also be done between affiliations or countries of co-authors. Network lines between the authors emphasize they have a relatively stronger connection due to their collaborations. Hence authors within similar colored clusters have close cooperative relationships with each other. Since, Boffetta, Stewart, and Leclerc contributed the highest three publications on the topic respectively; labels are greater than the other authors.

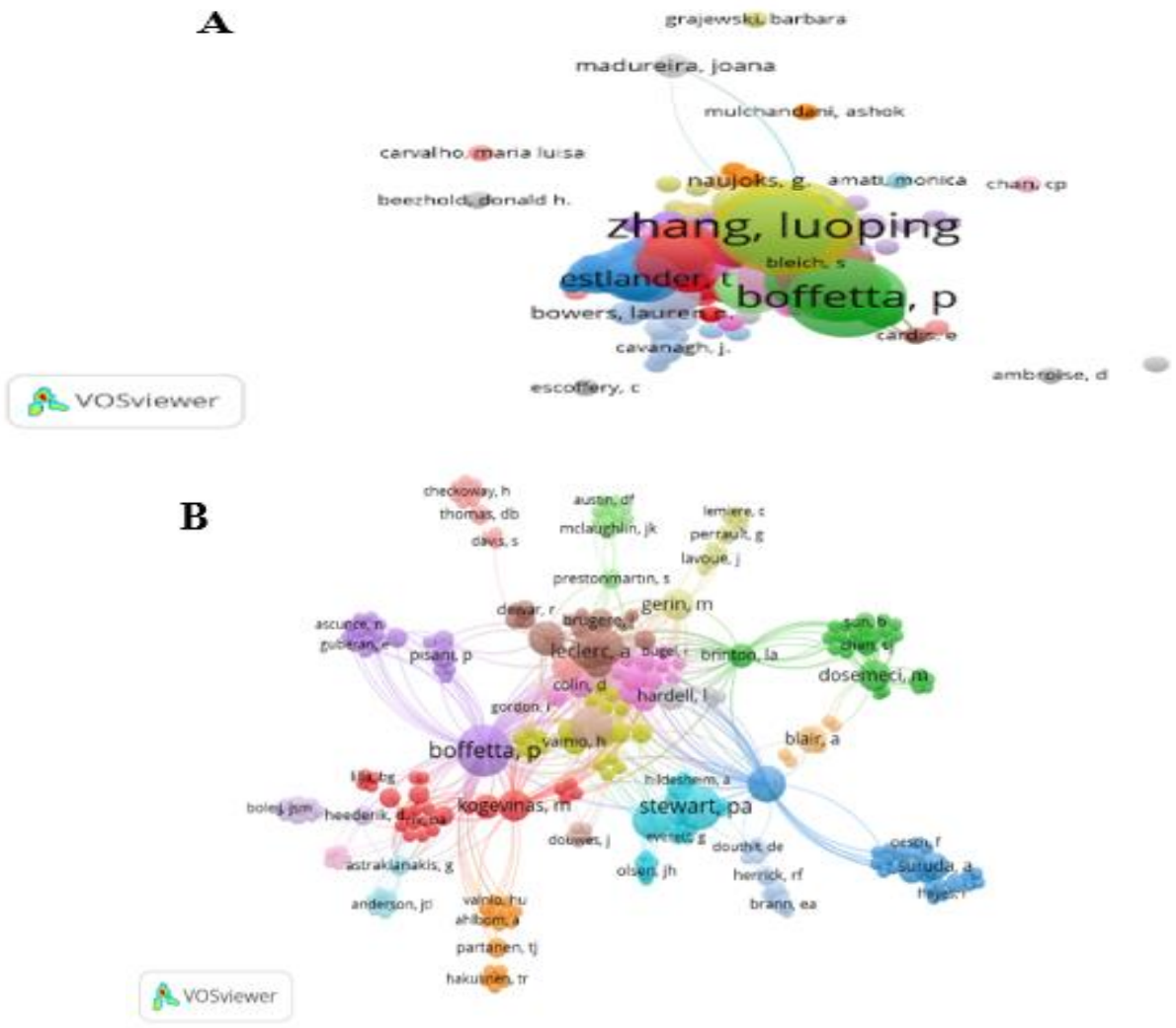

Figure 2. A) Bibliographic coupling of authors. B) Co-authorship of authors

Citation and co-citation analysis

The number of citations a scientific study receives is not only accepted as a measure of the publication's visibility, but also indicates that the publication has a high impact (Ugolini et al. 2015; Whipple et al. 2013; Chiu and Ho 2007). Citation analysis was conducted by examining the references found in the publications obtained from the query "occupational exposure to Formaldehyde." In 2390 publications on this topic, a total of 15253 references has been found. The annual average citation graph obtained using Bibliometrix is shown in Figure 3A. The increase, which started particularly in 1978, reached its highest level in 2012 with remarkably high momentum, resulting in approximately 12 citations per year.

Additionally, co-citation analysis provides an overview of the publications that are cited together, focusing on the relationship or interaction between these two publications. The more citations two publications share, the more similar they are assumed to be. The result of the co-citation analysis is shown in Figure 3B. The size of the nodes is directly proportional to the number of citations, and a smaller the distance between two publications signifies a stronger relationship. Nodes of the same color represent similar fields (Small 1973). When examining the co-citation analysis of highly cited references in publications related to the topic of "occupational exposure to Formaldehyde," five major clusters have been observed. The four authors cited over 150 times are Marsh, G.M., Blair, A., Zhang, L.P., and Hauptmann, M. These authors have been placed in blue and green clusters. While conducting this analysis in VOSviewer, the minimum number of citations received by the authors was limited to 15. Figure 3C shows which publications by these authors were cited.

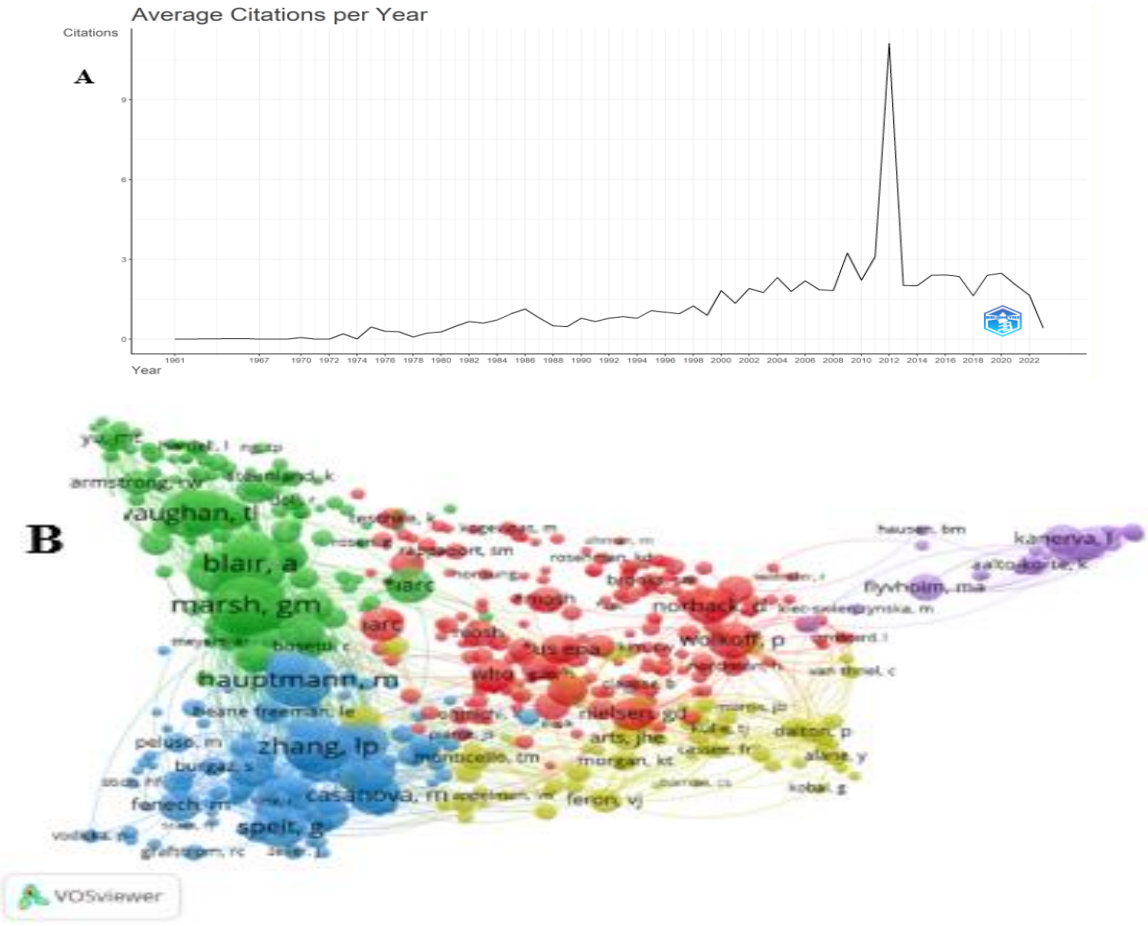

Figure 3. A) Average number of citations per year from 1960 to 2024. B) co-cited authors. C) co-cited references. D) keywords that appeared at least five times in publications related to the topic

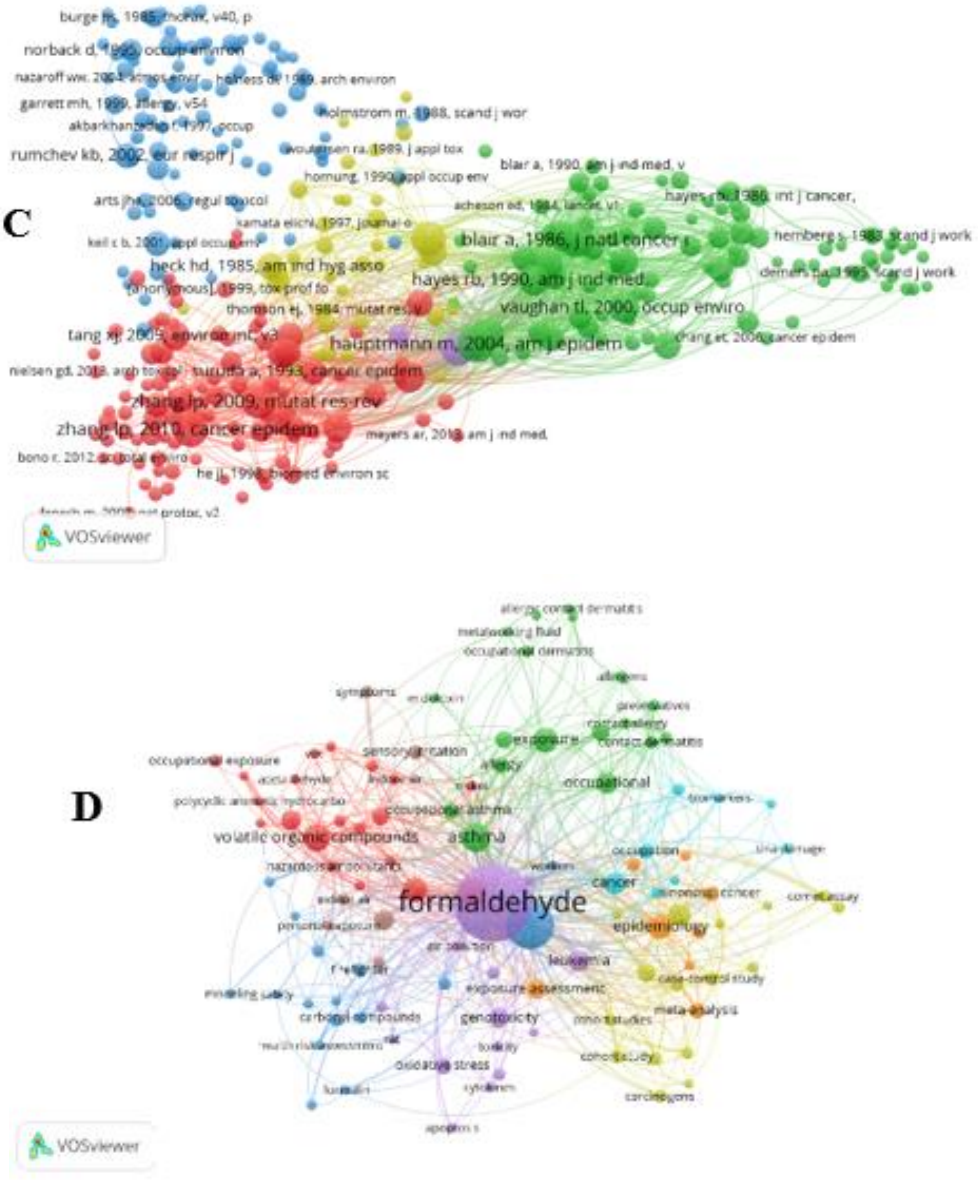

Figure 3. A) Average number of citations per year from 1960 to 2024. B) co-cited authors. C) co-cited references. D) keywords that appeared at least five times in publications related to the topic (Continued)

Publications and journals

It has been observed that 2390 scientific studies were published in 805 different journals. The high number of journal issues indicates the multidisciplinary nature of FA studies. Out of 805 journals, 518 (64.3%) published only one study on occupational exposure to Formaldehyde, while 106 (13.2%) published two studies, and 43 journals (5,3%) published ten or more scientific studies on the topic.

The most active journals publishing on "occupational exposure to Formaldehyde" and their impact factors are shown in Table 3. These 10 journals listed in the table constitute 1.2% of all journals published studies on the topic, while they contain 21.8% (n = 520/2390) of all published FA studies, which is more than one-fifth. Although the Journal of Contact Dermatitis has the highest number of publications and citations, the American Journal of Industrial Medicine ranks first in the h-index, and the Journal of Occupational and Environmental Medicine rank first in the g-index and m-index. The five journals with the greatest number of publications on the subject are compared in terms of their temporal distribution. The American Industrial Hygiene Association Journal reached the highest number of

publications in 1984 with seven publications, while the Journal of Contact Dermatitis followed this with six publications each in 2010 and 2021.

Table 3. The most active journals and impact factors on this subject

Source	NP	TC	h	g	m	PY_start
Contact Dermatitis	101	2852	32	48	0.653	1976
American Journal of Industrial Medicine	62	2417	33	48	0.805	1984
Occupational and Environmental Medicine	55	2787	31	52	1	1994
Journal of Occupational and Environmental Medicine	47	1358	21	36	0.5	1983
American Industrial Hygiene Association Journal	47	1103	18	32	0.367	1976
Annals of Occupational Hygiene	46	1176	22	33	0.344	1961
International Archives of Occupational and Environmental Health	44	1680	23	40	0.511	1980
Journal of Occupational and Environmental Hygiene	40	852	16	28	0.762	2004
Regulatory Toxicology and Pharmacology	39	1642	23	39	0.548	1983
Scandinavian Journal of Work. Environment and Health	36	1650	24	36	0.511	1978

NP: Number of publications; TC: total citation; PY_start: publication year start.

Terms analysis

For keyword analysis, the titles and abstracts of 2390 publications have been examined. Among the 4067 keywords, 167 words were found to be repeated at least five times. In the visual of Figure 3D, there are 8 main clusters. These clusters are primarily centered around the keywords "formaldehyde" and "occupational exposure," as well as the keywords "volatile organic compounds," "epidemiology," "asthma," and "cancer." Studies include the query “occupational exposure to Formaldehyde” conducted in various fields. In order to identify these fields, and observe research trends, it is necessary to analyze the statements in the title and abstract sections. When evaluating the results of the keyword analysis shown in Figure 3D, it should be noted that the size of the nodes is proportional to the frequency, and the distance between them indicates how often these words are used together. The shorter the distance between keywords, the stronger their relationship appears to be. Colors are used to represent different clusters.

The studies in the green cluster concentrate on the kinds of occupational disorders brought on by FA, according to our analysis of the researchers' research hotspots. The research in the red cluster looks at how compounds that are categorized as hazardous air pollutants, such as FA, affect air quality. The purple cluster is seen to be more concentrated on genotoxicity, toxicity caused by FA, and associated illnesses. While the keywords in the yellow cluster are more focused on statistical reviews, meta-analyses, and case-control studies, the keywords in the blue cluster are more focused on risk analysis and the evaluation of individual exposure in occupational groups.

CONCLUSION

In this study, a bibliometric analysis of occupational exposure to FA has been carried out. A search query for "occupational exposure to Formaldehyde" was conducted in the Web of Science and Scopus databases, and the obtained bibliometric outputs were analyzed using the VOSviewer and Bibliometrix programs.

Co-authorship and bibliographic coupling of countries and authors, co-citation cited authors and references, production and citation of affiliations and keyword analyses were conducted for 2390 studies published over 63 years in this study. They have been published in 26 different languages, with German sources being the most prevalent for FA studies after English. The USA ranks first in the list of countries with the most publications and the most cited studies on occupational exposure to Formaldehyde. Additionally, most of the top 10 institutions publishing studies on the topic are in the USA, with the

University of California ranking first. Five of the 10 authors who published the most studies on the subject work at American institutions. The American Journal of Industrial Medicine has the highest h-index, yet Contact Dermatitis has the most articles published. NIOSH, national and worldwide cancer research institutes, and academic institutions were among the top five most reported connections.

The four most influential authors in the field, each cited over 150 times, are Marsh, G.M., Blair, A., Zhang, L.P., and Hauptmann, M. Blair stands out as the most productive author on the topic of "occupational exposure to Formaldehyde" with 37 publications. He is also ranked first in the h-index ranking. With 2606 citations, Stewart P. is the most cited author. Considering the majority of all publications have multiple authors with an average of five, it appears that the authors focus on collaborative research. Although Zhang, L.P. and Boffetta, P.'s publication numbers are notable when examining the bibliometric coupling of the authors, the authors' proximity to each other in the clusters they belong to suggests a high probability of referencing similar publications. The three authors with the most publications are Blair, A., Stewart, P., and Boffetta, P. Furthermore, Boffetta, P., Stewart, P., and Leclerc, A. in particular have solid working relationships with other authors in their clusters.

According to the analysis of the most frequently repeated keywords in publications on the topic, the word “formaldehyde” is most often used in conjunction with the keywords “occupational exposure,” “volatile organic compounds,” “epidemiology,” “asthma,” and “cancer.” Looking at research trends, occupational diseases caused by FA; research into the effects of hazardous air pollutant chemicals classified as VOCs on air quality; the study of toxicity and related diseases; risk analysis and the assessment of occupational personal exposure stand out in line with statistical studies.

This study stands out as comprehensive research on occupational exposure to FA, examining all publications of most prestigious databases. Despite its comprehensive scope, this study has some limitations. The analysis was restricted to publications indexed in Web of Science and Scopus, which may exclude relevant studies from other databases. In addition, missing data such as full text, author names or addresses negatively affects the analysis. By using the findings of the analysis, researchers will be able to take a glance easily and emphasis trends of the topic. Furthermore, the study may guide researchers in identifying the points to focus on by revealing details about the most productive authors, affiliations, journals, countries and collaborations between them. These results provide a thorough overview of knowledge for researchers focused on this field. This study is believed to be a valuable alternative resource for understanding the global perspective on occupational exposure to FA and highlights areas for further investigation to the researchers aiming to work in this field.

Conflict of Interest

No potential conflict of interest was reported by the author(s).

Author’s Contributions

The authors declare that they have contributed equally to the article.

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