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Bibliometric Analysis

Research landscape on occupational hazards and pesticide exposure among agricultural workers: A bibliometric analysis

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Abstract

Occupational exposure to pesticides remains a significant public health concern for agricultural workers, with well-documented associations with both acute toxicity and long-term adverse health outcomes. The aim of this study was to systematically map and evaluate the global research landscape on occupational hazards and pesticide exposure among agricultural workers using a bibliometric approach. A bibliometric analysis was conducted using data retrieved from the Scopus database on August 4, 2025. A systematic search spanning 1963–2025 identified 7,173 records, of which 583 English-language journal articles met the inclusion criteria. Bibliometric mapping was performed using VOSviewer (version 1.6.20) to analyze publication trends, co-authorship networks, and keyword co-occurrence, supported by a controlled thesaurus to ensure term consistency. The findings demonstrate a sustained growth in research output over time, with publication activity peaking in 2021. The United States emerged as the leading contributor in terms of productivity and influence, followed by Brazil, the Netherlands, the United Kingdom, and India. Core research themes centered on pesticides, occupational exposure, agriculture, and agricultural workers. Although international collaboration networks were evident, contributions from several regions with high occupational risk remained limited. This study provides a comprehensive overview of global research trends, identifies established and emerging themes, and highlights critical knowledge gaps. These findings offer evidence-based insights to guide future research, strengthen international collaboration, and support policies aimed at improving occupational safety in agricultural settings.

Keywords: Occupational health, pesticide exposure, pesticide exposure, agricultural workers, bibliometric analysis

Introduction

Agriculture remains one of the most hazardous occupational sectors worldwide, with workers frequently exposed to multiple physical, chemical, and biological risks [1]. Among these, pesticide exposure represents one of the most critical and persistent concerns due to its widespread use and potential health impacts [2]. Pesticides are chemical agents designed to control pests and enhance crop yields, but their toxicological properties can also pose serious risks to human health [3]. Exposure may occur through inhalation of aerosols, dermal absorption, or ingestion of contaminated food and water [4]. Exposure levels vary across agricultural sectors, with pesticide applicators experiencing the highest risk; dermal contact accounts for up to 85–90% of the absorbed dose during field operations [5]. High rates of acute pesticide poisoning have been

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reported in horticulture (14–18%) and vegetable farming, driven by frequent and intensive pesticide use [6]. Rice farming is also associated with elevated exposure, with 30–45% of workers reporting acute pesticide-related symptoms during peak spraying periods [7]. Workers involved in mixing, loading, and application are particularly vulnerable, especially where personal protective equipment (PPE) is inadequate or inconsistently used [8]. These findings underscore the heightened vulnerability of specific agricultural subsectors and the need for targeted prevention strategies [9].

The health effects of pesticide exposure have been widely documented in epidemiological and toxicological studies [10]. Acute exposure may cause skin irritation, respiratory distress, headaches, nausea, and, in severe cases, poisoning requiring medical attention [11]. Chronic exposure has been associated with more serious outcomes, including neurodegenerative diseases, reproductive disorders, endocrine disruption, and certain cancers [12]. The World Health Organization (WHO) and the Food and Agriculture Organization (FAO) recognize pesticide poisoning as a major public health concern, particularly in low- and middle-income countries where safety regulations, training, and access to personal protective equipment (PPE) are often inadequate [13]. These limitations, combined with weak regulatory enforcement, further increase occupational health risks among agricultural workers [8].

Globally, pesticide use occurs on a massive scale, with millions of tonnes applied annually, primarily in agriculture [14]. While pesticides contribute to improved crop productivity and food security, their intensive use can lead to unintended health and environmental consequences [15]. Persistent residues in soil, water, and food chains create additional exposure pathways that extend beyond occupational settings, affecting families, communities, and ecosystems [16]. Balancing the benefits of pest control with the protection of human health and environmental sustainability remains a critical challenge.

Scientific research on occupational pesticide exposure in agriculture has expanded substantially over recent decades, with 583 publications included in the present analysis and a peak in annual output observed in 2021 [17]. However, this literature is fragmented across multiple disciplines, geographical contexts, and methodological approaches, making it difficult to obtain a coherent overview of research trends, thematic priorities, and knowledge gaps. To date, no bibliometric study has comprehensively examined this research field [18].

Bibliometric analysis provides a systematic and quantitative approach to addressing this gap by evaluating publication trends, citation patterns, collaboration networks, and thematic structures [19]. By evaluating publication and citation patterns, mapping co-authorship and keyword networks, and identifying influential authors, journals, and institutions, bibliometric methods can reveal both the historical trajectory and emerging trends in research [20]. The aim of this study was to provide a comprehensive bibliometric analysis of research on occupational health and pesticide exposure in the agricultural sector using Scopus data, in order to map the research landscape, identify major themes and collaboration patterns, and generate insights to inform future research and evidence-based policy interventions aimed at improving agricultural workplace safety.

Methods

Study design and bibliometric approach

This study employed a bibliometric analysis to systematically map the scholarly landscape and research trends related to occupational health and safety and pesticide exposure in the agricultural sector. Bibliometric analysis provides a quantitative approach for evaluating academic literature, enabling the identification of influential publications, thematic structures, collaboration patterns, and temporal trends within a research field [21]. In this study, bibliometric techniques were applied to examine the structural characteristics and developmental trajectory of research at the intersection of occupational health, pesticide exposure, and agriculture.

Data source and search strategy

The dataset was obtained exclusively from the Scopus database due to its broad coverage of peer-reviewed literature and robust citation-tracking capabilities. The literature search was conducted on August 4, 2025, using the following search string: ("occupational health" OR "occupational safety" OR "OHS" OR "workplace safety") AND ("pesticide" OR "pesticide exposure" OR "pest control") AND (agriculture OR farming OR "agricultural workers").

No time restrictions were applied, allowing retrieval of publications from 1963 to 2025. The initial search across all document fields yielded 7,173 records. Restricting the search to titles, abstracts, and keywords reduced the dataset to 809 records. Subsequent screening retained only relevant peer-reviewed journal articles published in English, resulting in a final dataset of 583 articles.

Eligibility criteria

Inclusion criteria comprised original research articles addressing occupational health and safety issues related to pesticide exposure in agricultural settings. Exclusion criteria included non-English publications, conference proceedings, book chapters, editorials, and studies not directly related to agriculture or pesticide exposure.

Data extraction

All bibliographic records were exported in CSV format for analysis. Data cleaning involved the removal of duplicate records and the standardization of author names, journal titles, and country names to ensure dataset consistency. A controlled thesaurus file was applied to author keywords in VOSviewer to harmonize synonymous terms (e.g., “pesticide” and “pesticides”) and incorporate alternative spellings, plural forms, and chemical names, thereby improving the accuracy of keyword co-occurrence analysis.

Bibliometric analysis and visualization

Bibliometric analyses were conducted using VOSviewer (version 1.6.20) to construct and visualize networks of co-authorship, keyword co-occurrence, citation relationships, and co-citation clusters. All network visualizations were generated using a minimum threshold of one for item inclusion and a minimum citation value of zero [22]. Indicators such as Total Link Strength, citation counts, document counts, and cluster groupings were used to assess scholarly influence and thematic relationships [23]. Descriptive statistics, including annual publication and citation trends, were also analysed to complement the network-based findings [24].

The processes of literature identification, screening, eligibility assessment, and final inclusion followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [25]. A summary of the study selection process is presented in **Figure 1**.

Results

Annual publications growth trends

Research on occupational health and safety related to pesticide exposure in the agricultural sector spans more than six decades, with the earliest identified publication dating back to 1963. From the 1960s through the late 1980s, publication activity remained sporadic, with fewer than five documents published annually in most years. A gradual increase emerged in the early 1990s, with annual output reaching double digits for the first time in 1992 (eight publications) and peaking at fourteen publications in 1999.

The early 2000s marked a period of more stable growth, during which annual publication counts consistently exceeded ten. Between 2008 and 2015, output ranged from seventeen to twenty-three publications per year, reflecting sustained scholarly attention to the topic. A pronounced surge was observed in 2021, when the number of publications increased to thirty-six, representing the highest annual output in the dataset. This increase coincided with heightened global attention to occupational health during the COVID-19 period; however, the specific drivers of this trend cannot be determined from bibliometric data alone [26]. In subsequent years, publication output fluctuated, declining to fourteen publications in 2023 before showing a modest recovery to seventeen publications in 2025 (**Figure 2**).

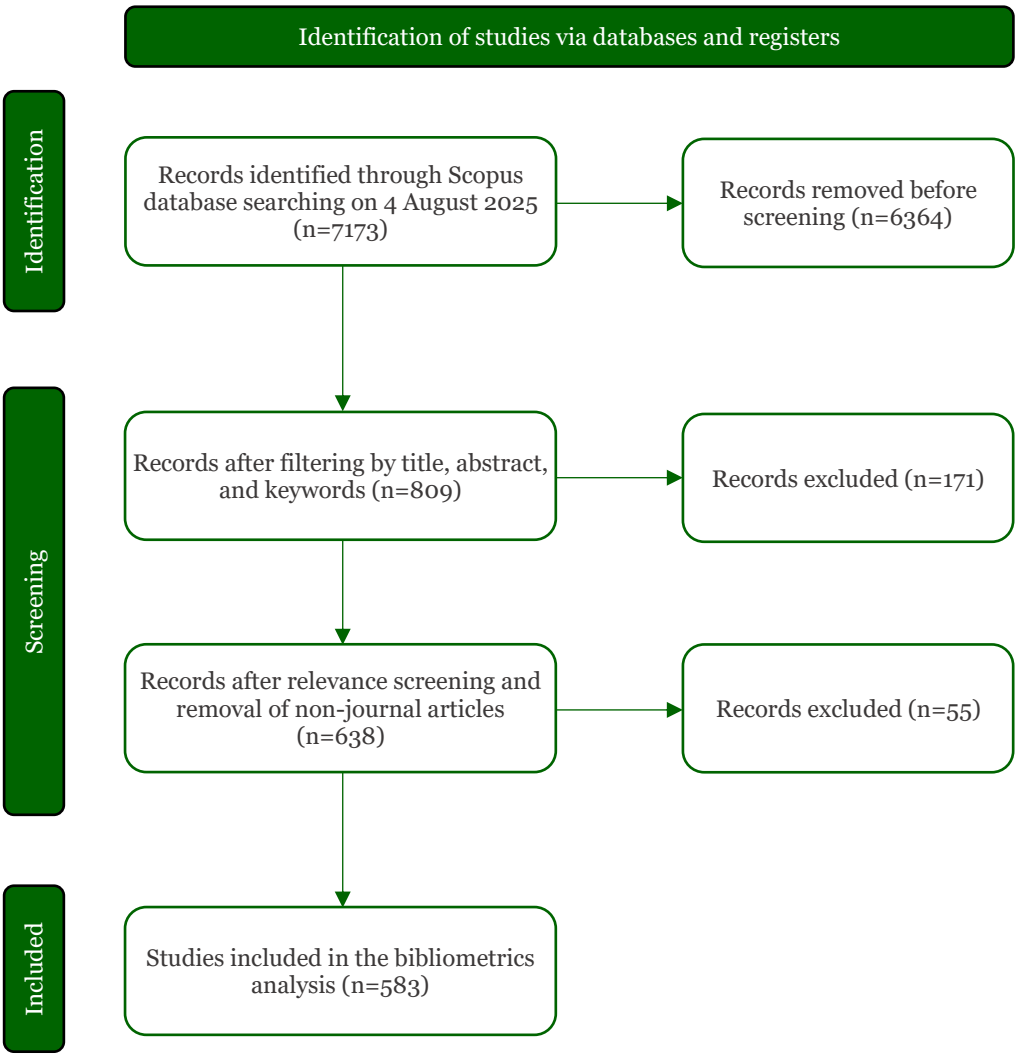

Figure 1. Flow diagram of the publication selection process from the Scopus database.

Citation trends broadly mirrored publication patterns but were also influenced by the age of the publications, as older studies have had more time to accumulate citations [27]. Publications from 1992 accumulated the highest total number of citations (992), indicating the lasting influence of research published during that period. Additional citation peaks were observed in 2017 (1,012 citations), 2011 (816 citations), and 2010 (766 citations). More recent publications generally exhibited lower citation counts, as expected due to their shorter citation windows; nevertheless, articles published in 2021 accrued a substantial 581 citations, suggesting rapid uptake and continued relevance (**Figure 3**).

These findings demonstrate a sustained long-term increase in both research output and scholarly influence, with particularly strong momentum over the past two decades. This trend underscores the continuing global importance of occupational pesticide exposure as a critical occupational health issue.

Most productive authors

Analysis of authorship patterns indicates that research on occupational health and safety related to pesticide exposure is concentrated among a relatively small group of highly productive scholars (**Table 1**). Thomas A. Arcury emerged as the most prolific author, with 26 publications, 1,228 citations, and a total link strength of 103, reflecting both high research output and extensive collaborative engagement. Sara A. Quandt followed closely with 25 publications and 1,205 citations and exhibited the highest total link strength (108) among the top five authors, indicating a central position within collaborative research networks.

Table 1. Most productive authors pesticide-related occupational health and safety research in the agricultural sector

Author	Documents	Citations	Total link strength
Arcury TA.	26	1228	103
Quandt SA.	25	1205	108
Chen H.	14	596	80
Grzywacz JG.	13	609	73
Sandler DP.	13	1041	44

Figure 2. Trends in annual publications on occupational health and pesticide exposure in agriculture (1963–2025).

Figure 3. Trends in annual citations of publications on occupational health and pesticide exposure in agriculture (1963–2025).

Haiying Chen ranked third, with 14 publications, 596 citations, and a total link strength of 80, reflecting consistent scholarly output and moderate network connectivity. Joseph G. Grzywacz contributed 13 publications, which accrued 609 citations and a total link strength of 73. Completing the top five, Dale P. Sandler also authored 13 publications but demonstrated a

substantially higher citation count (1,041), indicating the enduring influence of these contributions despite lower network connectivity (total link strength=44).

Network visualisation analysis shows that Arcury, Quandt, Chen, and Grzywacz belong to the same collaboration cluster, characterised by strong interconnections, as reflected by high link counts (16–21) and substantial total link strengths (73–108) (**Figure 4**). Their close proximity within the network indicates a tightly interconnected research group that has played a central role in shaping the literature. In contrast, Sandler appears in a separate cluster, suggesting involvement in a distinct research network with more limited integration into the primary collaboration structure.

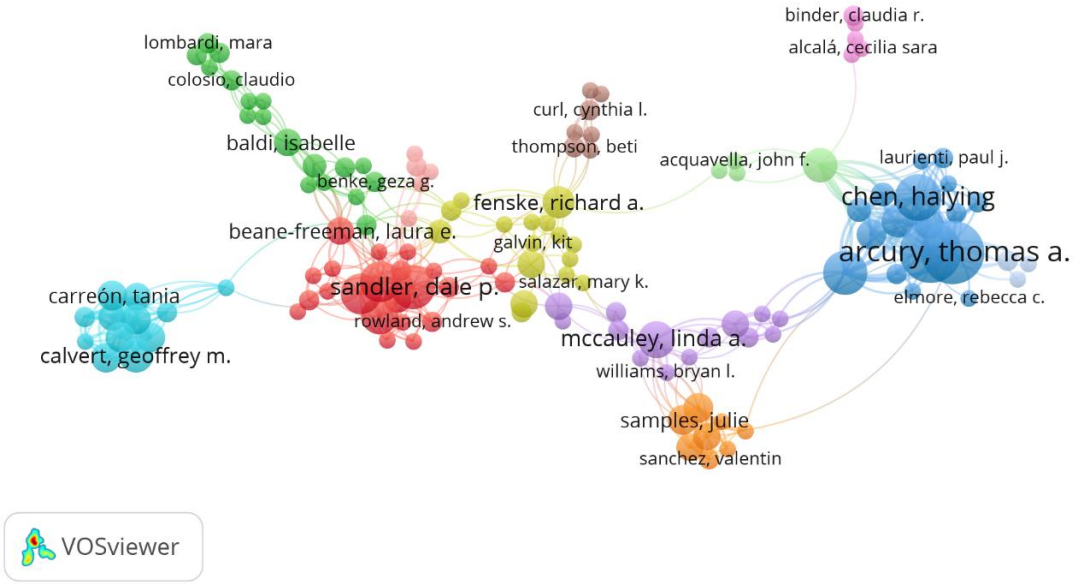

Figure 4. Co-authorship network visualisation of the most productive authors in pesticide-related occupational health research.

Highly cited authors

The five most highly cited authors in research on occupational health and safety related to pesticide exposure are presented in **Table 2**. Iavicoli (2017) ranks first, with 488 citations, representing the most influential single publication in the dataset. Semchuk (1992) follows with 400 citations, while Cantor (1992) ranks third with 321 citations. Acquavella (2004) occupies the fourth position with 260 citations, and Fall (1999) completes the top five with 236 citations.

Table 2. Most highly cited authors in occupational health and safety research related to pesticide exposure

Document	Citations	Links
Iavicoli (2017)	488	0
Semchuk (1992)	400	0
Cantor (1992)	321	0
Acquavella (2004)	260	0
Fall (1999)	236	0

Network visualisation analysis indicates that none of the five highly cited authors have recorded co-authorship links within this dataset (**Figure 5**). This finding suggests that their influential publications were produced independently rather than as part of active collaborative networks, as captured by VOSviewer [28].

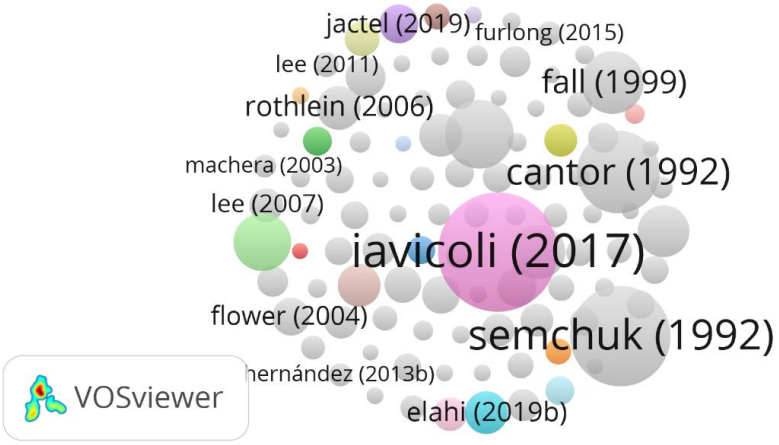

Figure 5. Citation network visualisation of the most highly cited authors in pesticide-related occupational health research.

Country-level contributions

The five leading countries contributing to research on occupational health and safety related to pesticide exposure is presented in **Table 3**. The United States is the most prolific contributor, with 230 publications and 8,433 citations. It also exhibits the highest total link strength (68), reflecting strong international collaboration, supported by 35 recorded co-authorship links that position the country as a central hub within the global research network.

Table 3. Leading countries in pesticide-related occupational health and safety research in the agricultural sector

Country	Documents	Citations	Total link strength
United States	230	8433	68
Brazil	43	580	5
Netherlands	29	855	38
United Kingdom	28	1076	35
India	26	418	8

Brazil ranks second, with 43 publications and 580 citations. Despite its relatively high research output, Brazil demonstrates low international collaboration, as indicated by a total link strength of 5, suggesting limited integration within the global research network. The Netherlands ranks third, contributing 29 publications and 855 citations, and exhibits strong connectivity, with a total link strength of 38 across 23 links, reflecting an active collaborative research approach that may enhance citation impact. The United Kingdom ranks fourth, with 28 publications and 1,076 citations, and shows a comparable collaboration profile, with a total link strength of 35 and 22 links. India ranks fifth, contributing 26 publications and 418 citations, and demonstrates modest international engagement, with a total link strength of 8 across 7 links. Network visualisation analysis highlights the central role of the United States in the global co-authorship network, while indicating that countries such as Brazil and India remain less connected to the core group of internationally collaborative research (**Figure 6**).

Institution analysis

The five most productive journals publishing research on occupational health and safety related to pesticide exposure is listed in **Table 4**. The Journal of Agromedicine ranks first, with 32 publications and 623 citations. It also demonstrates a high total link strength (264 across four links), reflecting frequent co-citation with other journals and underscoring its role as a key outlet for research at the intersection of agriculture and health.

The International Journal of Environmental Research and Public Health ranks second, contributing 26 publications and 655 citations. Although its total link strength (131) is lower than that of the Journal of Agromedicine, it remains an influential source due to its broad environmental health focus and substantial citation impact.

Table 4. Leading journals in pesticide-related occupational health and safety research in the agricultural sector

Source	Documents	Citations	Total link strength
Journal of Agromedicine	32	623	264
International Journal of Environmental Research and Public Health	26	655	131
American Journal of Industrial Medicine	25	937	408
International Journal of Occupational and Environmental Health	17	492	117
Journal of Agricultural Safety and Health	15	355	203

In third position, the American Journal of Industrial Medicine contributed 25 publications and recorded the highest citation count among the top five (937). It also exhibits the strongest co-citation connectivity, with a total link strength of 408 across five links, highlighting its central role in occupational health research. The International Journal of Occupational and Environmental Health follows with 17 publications and 492 citations, along with a total link strength of 117 from three links, indicating a moderate yet meaningful contribution to the field. Rounding out the top five, the Journal of Agricultural Safety and Health published 15 articles and accrued 355 citations. Despite a smaller publication volume, it shows relatively high network integration, with a total link strength of 203 across seven links.

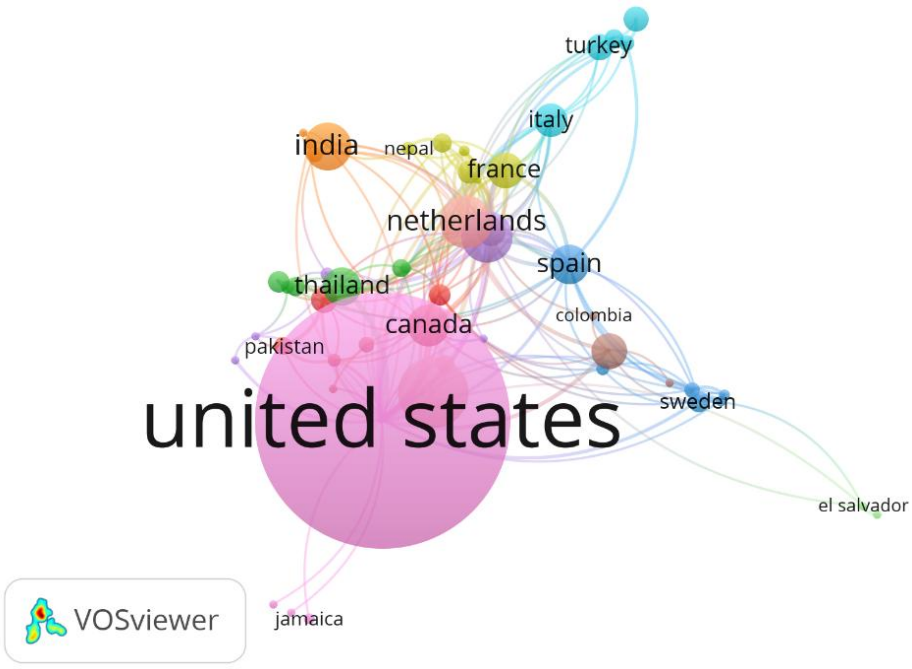

Figure 6. Co-authorship network visualisation of the most productive countries in pesticide-related occupational health research.

Network visualisation analysis shows that the leading sources form distinct yet interconnected clusters, with the *American Journal of Industrial Medicine* functioning as a central co-citation node that links specialised agricultural health journals with broader occupational and environmental health publications (**Figure 7**).

Analysis of key research themes

Co-occurrence analysis was used to identify the most frequently occurring keywords in the literature on occupational health and safety related to pesticide exposure, with "pesticide" emerging as the most dominant keyword, appearing 488 times and exhibiting the highest total link strength (TLS=9,269) (**Table 5**). In this analysis, TLS represents the cumulative strength of keyword co-occurrence relationships within the network rather than the number of individual

connections. The term also recorded 998 links, indicating its role as the central thematic hub and its strong association with nearly all other major concepts in the research field.

Table 5. Most frequently co-occurring keywords in pesticide-related occupational health and safety research in the agricultural sector

Keyword	Occurrences	Total link strength
Pesticide	488	9269
Occupational Exposure	378	7957
Occupational Health	357	6995
Agriculture	330	6525
Agricultural Worker	329	7039

The second most frequent keyword, “occupational exposure,” appeared 378 times and exhibited a high total link strength (TLS=7,957), indicating strong thematic connectivity within the co-occurrence network. It belongs to Cluster 9, which primarily encompasses terms related to exposure pathways, risk assessment, and workplace monitoring. With 993 links, this keyword serves as a bridge between toxicological and epidemiological research in occupational health. “Occupational health” ranked third, with 357 occurrences, a TLS of 6,995, and 979 links. Located in Cluster 3, this keyword anchors discussions on worker well-being, disease prevention, and health services in agricultural settings.

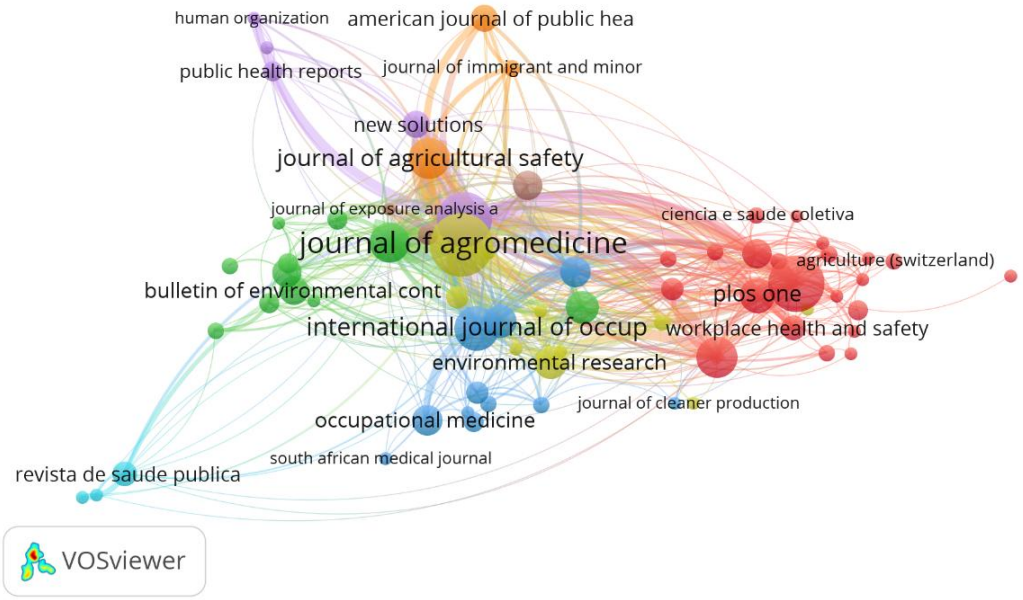

Figure 7. Co-citation network visualisation of the leading journals in pesticide-related occupational health research.

The keyword “agriculture” followed closely, appearing 330 times with a TLS of 6,525 and 949 links. Also assigned to Cluster 3, it underscores the central role of agricultural contexts in shaping occupational risk profiles, particularly in low- and middle-income countries where pesticide use is widespread. “Agricultural worker” ranked fifth with 329 occurrences and demonstrated a higher TLS (7,039) than “agriculture.” Positioned in Cluster 2, it reflects a thematic focus on the human dimensions of exposure, including workforce characteristics, labour conditions, and protective practices.

Network visualisation analysis shows that these keywords are highly interconnected, while their cluster assignments reveal distinct yet overlapping thematic substructures. Pesticide-related terms (Cluster 2) are strongly linked to human-centred occupational health themes (Clusters 3 and 9), forming a dense conceptual core of the research field (**Figure 8**).

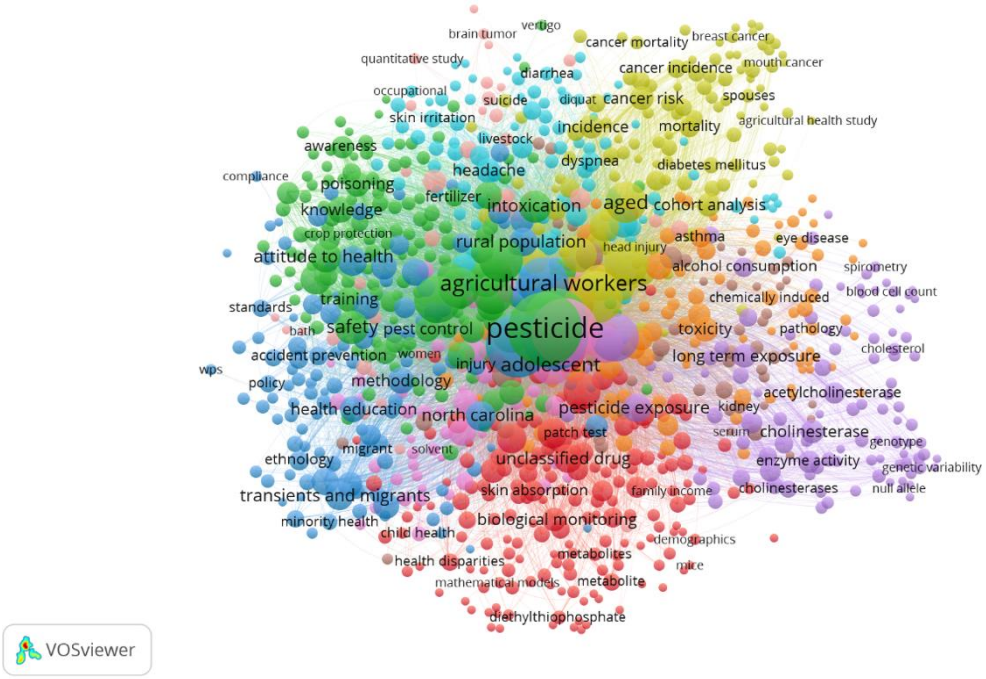

Figure 8. Keyword co-occurrence network visualisation in pesticide-related occupational health and safety research.

Discussion

This bibliometric analysis illustrates the evolution and structural characteristics of research at the intersection of occupational health, pesticide exposure, and agriculture. Trends in publication and citation output indicate a gradual increase in scientific activity from the 1960s, followed by a more pronounced acceleration beginning in the early 1990s. This pattern is consistent with broader global trends reported in the literature, which attribute increased research attention to growing recognition of occupational risks in agriculture, advances in epidemiological methods, and improvements in health surveillance systems. The marked peak in publication output observed in 2021 aligns with reports of heightened global attention to essential workers and agricultural supply chains during the COVID-19 pandemic, which may have stimulated increased scholarly focus on workplace safety and health protection. Nevertheless, it is important to note that bibliometric data alone cannot establish causality; these interpretations are therefore informed by existing literature rather than derived directly from the present analysis [29].

Analysis of authorship patterns highlights the central contributions of highly productive scholars such as Arcury, Quandt, and Chen, whose work has substantially advanced understanding of pesticide-related health risks among agricultural workers. Their research spans epidemiological investigations, exposure assessments, and community-based interventions, often conducted within well-established collaborative networks. Their prominent positions within the co-authorship network, reflected by high total link strengths, underscore both their productivity and their influence in shaping the field through sustained collaboration. In contrast, the most highly cited publications, including those by Iavicoli (2017) and Semchuk (1992), demonstrate that individual landmark studies can exert enduring influence despite lower publication volume. This finding highlights the importance of methodological rigor, innovative study designs, and comprehensive analyses in generating long-term scholarly impact.

At the country level, the dominance of the United States likely reflects its extensive research infrastructure and long-standing investment in occupational health research rather than a direct causal relationship. Other major contributors, including Brazil, the Netherlands, and the United Kingdom, similarly reflect regional priorities where agriculture plays a significant economic and social role. However, the limited representation of countries with high pesticide use but lower research capacity—particularly in Southeast Asia and parts of Africa—reveals a persistent

geographical imbalance in research output. This disparity underscores the need for stronger international collaboration and capacity-building initiatives to ensure that research more accurately reflects global exposure patterns and occupational risks.

The analysis of leading sources further emphasizes the importance of specialized journals in shaping the research agenda. Journals such as the *Journal of Agromedicine* and the *American Journal of Industrial Medicine* function as core publication platforms, integrating perspectives from occupational medicine, environmental health, toxicology, and agricultural sciences. Their prominence highlights the value of multidisciplinary approaches in addressing the complex and context-specific health challenges associated with pesticide exposure in agriculture.

Keyword co-occurrence analysis confirms a strong thematic concentration within the field, with "pesticide," "occupational exposure," "occupational health," "agriculture," and "agricultural worker" forming the conceptual core. These keywords capture both the primary hazard and the occupational context in which exposure occurs, linking toxicological concerns with broader occupational health frameworks. The use of a controlled thesaurus to standardize keywords reduced semantic fragmentation and allowed related concepts, including different pesticide classes, to be analysed cohesively, thereby enhancing the clarity and interpretability of thematic clusters.

Overall, the findings indicate that research on occupational health and pesticide exposure in agriculture has reached a mature yet evolving stage. Important gaps remain, including limited longitudinal evidence on chronic health outcomes, underrepresentation of low-income agricultural regions, and insufficient evaluation of preventive and policy interventions across diverse agricultural systems. Addressing these gaps will require stronger global research networks, particularly through the inclusion of underrepresented regions, to develop a more comprehensive and equitable understanding of occupational health risks faced by agricultural workers worldwide.

Conclusion

This bibliometric analysis provides an overview of global research on occupational health and safety related to pesticide exposure in agriculture over the past six decades. The steady increase in publications reflects growing scholarly attention to pesticide-related occupational risks. Research output and collaboration are dominated by the United States, while countries with high pesticide use but limited research capacity remain underrepresented. The literature is thematically centred on pesticides, occupational exposure, and agricultural workers. Addressing existing gaps will require strengthening research capacity in underrepresented regions, fostering interdisciplinary collaboration, and advancing studies on long-term health effects and policy-relevant interventions to improve occupational health and safety in agricultural settings.

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Competing interests

There is no conflict of interest in the present study for any of the authors.

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Underlying data

All underlying data have been presented in this article.

Declaration of artificial intelligence use

Artificial intelligence (AI) tools (ChatGPT) were used solely for language refinement, including improving grammar, sentence structure, and readability of the manuscript. All AI-assisted

processes were critically reviewed by the authors, and the final decisions and interpretations presented in this article were made exclusively by the authors.

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