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Review Article

A Systematized Overview of Published Reviews on Biological Hazards, Occupational Health, and Safety

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ABSTRACT

Introduction: The COVID-19 pandemic turned biological hazards in the working environment into a global concern. This systematized review of published reviews aimed to provide a comprehensive overview of the specific jobs and categories of workers exposed to biological hazards with the related prevention.

Methods: We extracted reviews published in English and French in PubMed, Embase, and Web of Science. Two authors, working independently, subsequently screened the potentially relevant titles and abstracts recovered (step 1) and then examined relevant full texts (step 2). Disagreements were resolved by consensus. We built tables summarizing populations of exposed workers, types of hazards, types of outcomes (types of health issues, means of prevention), and routes of transmission.

Results: Of 1426 studies initially identified, 79 studies by authors from every continent were selected, mostly published after 2010 ($n = 63$, 79.7%). About half of the reviews dealt with infectious hazards alone ($n = 38$, 48.1%). The industrial sectors identified involved healthcare alone ($n = 16$), laboratories ($n = 10$), agriculture (including the animal, vegetable, and grain sectors, $n = 32$), waste ($n = 10$), in addition of 11 studies without specific sectors. The results also highlighted a range of hazards (infectious and non-infectious agents, endotoxins, bioaerosols, organic dust, and emerging agents).

Conclusion: This systematized overview allowed to list the populations of workers exposed to biological hazards and underlined how prevention measures in the healthcare and laboratory sectors were usually well defined and controlled, although this was not the case in the agriculture and waste sectors. Further studies are necessary to quantify these risks and implement prevention measures that can be applied in every country.

1. Introduction

Biological hazards, both infectious and non-infectious, constitute significant threats to health in numerous industrial sectors and workplaces around the world, often leading to occupational and work-related diseases [1–4]. During the COVID-19 pandemic, controlling biological risks in working environments became a global priority and revealed the urgent need to develop standards and guidelines for managing them [5]. In the context of drafting technical guidelines on biological hazards for the International Labor Organization, the importance of having a global vision has been stressed, and in particular, the need of a systematic view of the occurrence of biological risk in the workplace, with an inventory of the jobs and categories of workers exposed to it and related

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prevention measures. We, therefore, aimed to perform a systematized overview of the scientific literature in this domain to identify the specific jobs and categories of workers exposed to biological hazards.

2. Methods

Our review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement [6]. We searched the PubMed, EMBASE, Web of Science, and academic electronic databases without date limits until August 2022. Our search strategy was designed by the researchers and specialist librarians to optimize the string (see Appendix 1).

Because our review was to focus on review articles about biological hazards and occupational health, our research sought selected keywords in article titles and abstracts. The term 'review' was considered a keyword rather than a filter to increase the search's sensitivity since we did not only include systematic reviews. We did not exclude any languages in the first selection so as to quantify the total number of reviews and their languages, though only articles in French and English were included in the next stage. Study selection was made using Covidence software (https://www.covidence.org/). All the study records identified in the search were downloaded, and duplicates were identified and deleted. Next, two review authors, working independently (AO, AD), screened the titles and abstracts of potentially relevant articles (step 1) and then examined their full texts (step 2). In step 1, we excluded irrelevant studies (i.e., do not fit inclusion criteria, including wrong study design, population, or setting). Disagreements on which articles should be included were resolved by consensus between the two authors.

In addition to the first author's name, the year of publication, nationality of the first author author's, and the review's design, we also extracted the article's PECO criteria (Population, Exposure, Comparison, Outcome). We also recorded the populations of exposed workers, types of hazards, types of outcomes (types of health issue, means of prevention), and routes of transmission. The review's protocol was registered in PROSPERO as CRD42022351533.

3. Results

We found 1,426 studies corresponding to our inclusion criteria in the three databases. After eliminating the duplicates ($n = 567$), 859 studies remained at this first selection step, and 79 of these were included in the final round (Fig. 1, [3,4,13–89]).

Most of the studies were published after 2010 ($n = 63$, 79.7%), and they concerned a broad diversity of countries and every continent (Europe, $n = 40$; the Americas, $n = 22$; Asia, $n = 10$; Africa, $n = 4$; and Oceania, $n = 3$). Systematic reviews represented less than 40% of the published reviews (2 scoping reviews, 29 systematic reviews), and the others were non-systematic reviews ($n = 48$). About half of the reviews dealt with infectious hazards only ($n = 38$,

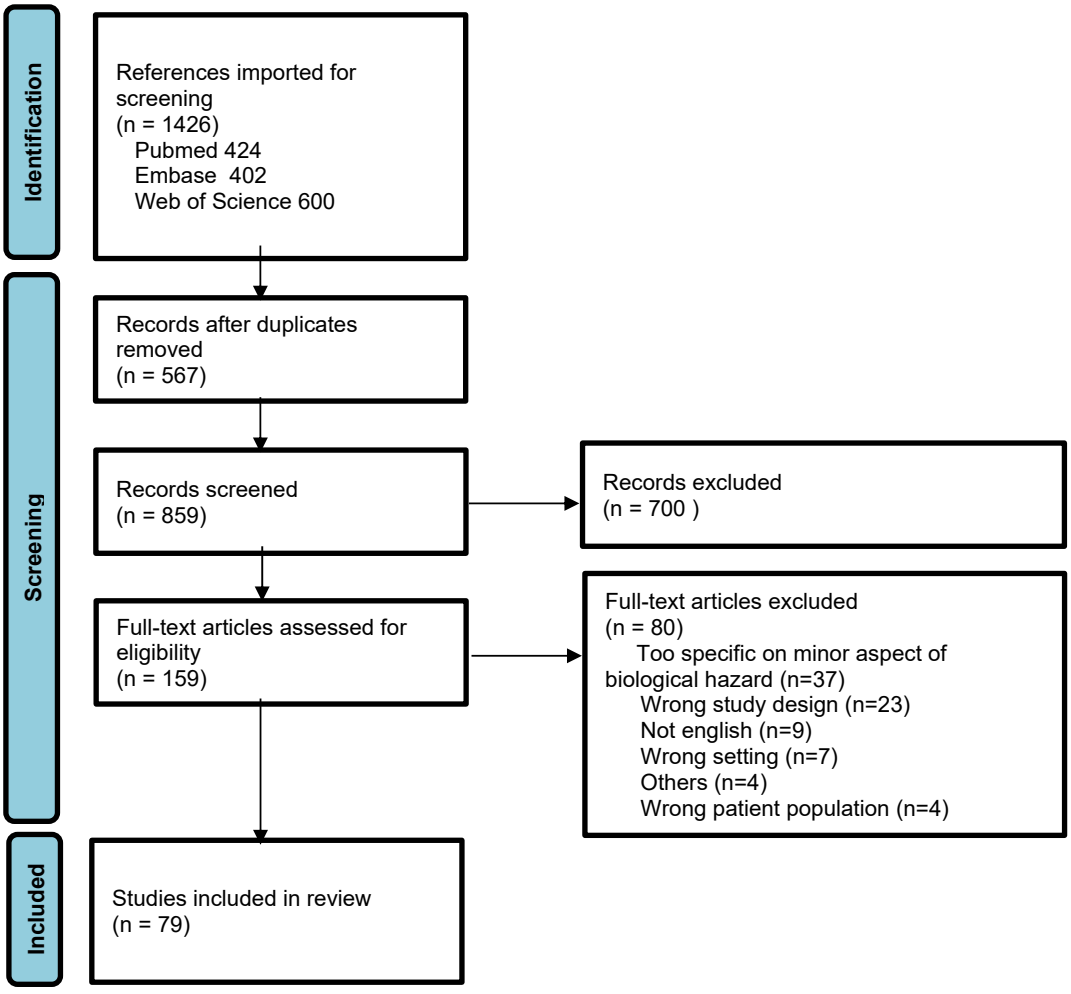

Fig. 1. Flow diagram of study selection.

48.1%), 24 focused on non-infectious hazards only (30.4%) and 17 included both infectious and non-infectious hazards (21.5%).

Summaries of the sectors of economic activity identified in the review process are presented in Tables 1–5: all sectors (n = 11, with some focus or exclusion, Table 1), healthcare workers only (n = 16, Table 2), laboratories (n = 10, Table 3), agriculture (including animal, vegetable and grain sectors, n = 32, Table 4), and waste (n = 10, Table 5). Tables 1–5 are notable because of the large number of different hazards considered (infectious and non-infectious agents, endotoxins, bioaerosols, and organic dust). The most frequently reported health outcomes were infections and respiratory symptoms. Some papers discussed transmission routes and preventive measures.

Reviews involving healthcare workers described many professions, from nurses to dentists, including different specialties (e.g., emergency, intensive care, and pathology) to illustrate the diversity of potential exposures in the healthcare sector (Table 2). Reviews involving laboratory workers detailed laboratory-acquired infections and injuries, such as needle sticks, cut, and scrapes, and provided information on prevention procedures or biosafety guidelines (Table 3). Agricultural sector reviews included animal farmers, animal food industry workers, veterinarians, abattoir workers, grain industry workers, cannabis industry workers and, by extension, professions working with trees (e.g., forestry, sawmill industries) and plant-based textiles (e.g., cotton, other non-synthetic textiles) (Table 4). Reviews involving waste industries included wastewater treatment plant workers, composting workers, and solid-waste handlers (in collecting, sorting, and treatment) (Table 5).

4. Discussion

This systematized overview provides a comprehensive description of the published academic works describing populations of workers exposed to biological hazards, including information on preventive and safety measures implemented for them.

In the healthcare and laboratory sectors, the importance of emerging hazards (new pathogens and new technologies) was stressed long before the COVID-19 pandemic, with a focus on anticipating potential risks at 15, 25, 26, 38, 56, 67, 73, 90. At the same time, workers in these sectors are also exposed to known biological hazards, such that basic precautions and preventive measures should already be applied continuously (e.g., safety procedures, vaccination), not only in industrialized countries but worldwide.

In the agriculture and waste sectors, workers are mainly exposed to organic dust and bioaerosols. A bioaerosol is an airborne collection of biological material. They can be composed of bacterial cells and cellular fragments (endotoxins), fungal spores and fungal hyphae, viruses, and the by-products of microbial metabolism. Pollen grains and other biological material can also be airborne as bioaerosols [1]. Of the various biological substances present in bioaerosols, only endotoxins (lipopolysaccharides of the walls of gram-negative bacteria) have an OEL of 90 EU/m^3 for an 8-hours work exposure, proposed by Dutch Expert Committee on Occupational Standards. In animal farming (pig, dairy, horse and poultry farming), the average levels of personal exposure to endotoxins vary from 220 to 9,609 EU/m^3, with a maximum of 374,000 EU/m^3 measured in pig farming [17]. In the grain sector, average concentration of 1,115 EU/m^3 is observed, while it reached 1,800 EU/m^3 in the seed processing sector, with medians of 56,000 and 160,000 EU/m^3 for grain storage and dried grass processing, respectively. In the cotton sector, the averages were from 20 to 4,850 EU/m^3, with maximum of 30,450 EU/m^3,

Table 1
Studies looking at all sectors

Study_ID	Nationality of the first author	Review type	Infectious/ Non-infectious	Activity sectors/ populations	Hazards	Modes of transmission	Health outcomes	Prevention guidelines (yes/no)
Acke_2022	The Netherlands	Systematic	Infectious	All except healthcare occupations	All pathogenic agents	Aerosols, direct contact, percutaneous	Infection	No
Douwes_2003	The Netherlands (with USA)	Non-systematic	Infectious and non-infectious	All except healthcare occupations	Bioaerosols	Aerosols	Respiratory symptoms, infections, allergy	Yes (minor)
Dutkiewicz_ 1988	USA (with Poland)	Non-systematic	Infectious and non-infectious	All	Biohazards	Aerosols and direct contact	Infections, respiratory symptoms, allergy	No
Farokhi_2018	The Netherlands	Systematic	Non-infectious	All	Endotoxins	Aerosols	Respiratory symptoms	No
Franco_2020	Brazil (with Pakistan)	Systematic	Non-infectious	All	Toxigenic fungi and mycotoxins	Aerosols, direct contact	Respiratory symptoms and toxic effects	No
Haagsma_2012	The Netherlands	Systematic	Infectious	All	All pathogens (Tables 1+3)	All (Tables 2+3)	Not specified	No
Liebers_2006	Germany	Non-systematic	Non-infectious	All with a focus on agriculture, textile industry, wood processing industry, waste collection	Endotoxins	Aerosols	Respiratory symptoms, organic dust toxic syndrome	No
Liebers_2020	Germany	Systematic	Non-infectious	All	Endotoxins	Aerosols	Respiratory symptoms, organic dust toxic syndrome	No
Montano_2014	Germany	Non-systematic	Infectious	All	50 pathogens (, appendix)	Not detailed	All	No
Payton_2000	UK	Non-systematic	Infectious	All/focus on healthcare workers	Hepatitis B/C and HIV	Percutaneous	Infection	No
Rim_2014	Republic of Korea	Non-systematic	Infectious	All	All pathogenic agents	Aerosol, direct contact/ percutaneous	Infection	Yes (engineering, management, training, PPE)

Table 2
Studies focused on healthcare workers

Study ID	Nationality of the first author	Review type	Infectious/ Non-infectious	Activity sectors/ populations	Hazards	Modes of transmission	Health outcomes	Prevention guidelines (yes/no)
Andrion_1994	Italy	Non-systematic	Infectious	Healthcare workers	All (TB, Hepatitis, HIV, …)	Not specified	Infection	Yes (organization, education, occupational health)
Barchitta_2019	Italy	Non-systematic	Infectious	Healthcare workers	Vaccine-preventable diseases	Not specified	Infection/vaccination	Yes (vaccination)
Brewczyńska_2015	Poland	Non-systematic	Infectious	Healthcare workers (emergency medical personnel)	Infectious (mostly), but allergens mentioned	Aerosols, direct contact, percutaneous (bloodborne infections, airborne infection, direct and indirect contact infection mostly)	Infection (mostly), but immunity disorders (asthma) mentioned	No
Dearaujo_2022	Brazil	Systematic	Infectious	Healthcare workers	Respiratory biological agents (SARS, influenza)	Aerosol	Infection (potential)	Yes (effectiveness of masks)
Díaz-Guio_2020	Columbia (with Germany)	Non-systematic	Infectious	Healthcare workers (intensive care)	SARS CoV-2	Aerosols/droplets, direct-indirect contact	Infection	Yes (PPE, procedure, skills/knowledge)
Fyumagwa_2011	Tanzania	Non-systematic	Infectious	Healthcare workers and livestock workers if epidemic	Phlebovirus	Percutaneous	Rift Valley Fever	Yes (in case of epidemic = health message, PPE, surveillance)
Leggat_2007	Australia (Thailand and Japan)	Non-systematic	Infectious	Healthcare workers (Dentists)	Infectious	Aerosols, direct contact, percutaneous	Infection	Yes (sterilisation/PPE)
Low_2005	Singapore	Non-systematic	Infectious	Healthcare workers	Respiratory hazards	Aerosols/droplets	Respiratory infection (influenza, pertussis, tuberculosis, SARS)	Yes (early identification and precautions, education, vaccination, research)
Monteiro_2022	Portugal	Systematic	Infectious	Healthcare workers	Bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus* spp., *Staphylococcus aureus* and *Micrococcus luteus*)	Aerosols, direct contact	Infection	No
Pedrosa_2011	Brazil	Systematic	Infectious	Healthcare workers and laboratory workers	Virus	Aerosol, direct contact/percutaneous	Infection	Yes (biosafety procedures)
Rai_2021	Australia (with Bhutan)	Scoping	Infectious	Healthcare workers	Bloodborne pathogens and tuberculosis	Percutaneous and respiratory	HIV, hepatitis and tuberculosis	No
Ridge_2019	USA	Systematic	Infectious	Healthcare workers (Nurse)	Bloodborne pathogens	Percutaneous	Not detailed	Yes (training, PPE mostly)
Szymanska_2012	Poland	Non-systematic	Infectious	Healthcare workers (Dentist)	Bacterial hazards	Aerosols, direct contact, percutaneous	Bacterial infection	No
Tan_1991	Malaysia	Non-systematic	Infectious	Healthcare workers (Nurse)	Biological hazards (Hepatitis B/C, HIV, tuberculosis, CMV, herpes, clostridium difficile)	Aerosols, direct contact, percutaneous	Infection	No
Trevisan_2015	Italy	Non-systematic	Infectious	Healthcare workers	Hepatitis B	Percutaneous	Hepatitis B	Yes (vaccination)
Zemouri_2017	The Netherlands	Scoping	Infectious	Healthcare workers (hospital and dental environment)	Biological hazards via bioaerosols	Bioaerosols	Infection	No

Table 3
Studies focused on laboratories

Study_ID	Nationality of the first author	Review type	Infectious/ Non-infectious	Activity sectors/ population	Hazards	Modes of transmission	Health outcomes	Prevention guidelines (yes/no)
Andrup_1990	Denmark	Non-systematic	Both infectious and not infectious	Laboratory/Industries with use of recombinant DNA	Microbiological/ endo-exotoxin contamination	Aerosols, direct contact	Not detailed	Yes (containment, medical surveillance, regulation)
Artika_2017	Indonesia	Non-systematic	Infectious	Laboratory (with emerging virus)	Emerging virus in 2017 (table 1)	Not specified	Infection	Yes (biosafety with containment, procedures, protection, biosecurity)
Coelho_2015	Portugal	Non-systematic	Infectious	Laboratory	All (Brucella, mycobacterium tuber, Neisseria, parasites and viruses)	Aerosols, direct contact	Infection	Yes (regulation, biosafety biosecurity, organization, training)
Collins_2017	USA	Non-systematic	Infectious	Laboratory animal research	Viral vectors	Direct contact, Percutaneous (with biological fluids, bite, scratch)	Not specified	Yes (regulation, risk assessment, procedures)
Ghosh_2020	USA	Non-systematic	Infectious	Laboratory (using viral vectors systems for gene therapy)	Viral vectors	Not specified	Not specified	Yes (biosafety rules validation Table 1 and Figure 1)
Gomez-Tatay_2019	Spain	Non-systematic	Infectious	Laboratory (Synthetic Biology)	Synthetic Biology	Not specified	Not specified	Yes (biosafety Table 1, biosecurity, regulation)
Hankenson_2003	USA	Non-systematic	Infectious	Laboratory animal research	Zoonotic agents	Aerosols, direct contact, percutaneous	Zoonosis	Yes
Pastorino_2017	France	Non-systematic	Infectious	Laboratory	Infectious (CL-3, infectious agents or toxins that may be transmitted through the air and cause potentially lethal infections)	Aerosol, direct contact/ percutaneous	Infection	Yes (biosafety with material/technical, PPE, waste management, disinfection and regulation)
Peng_2018	China (with Mexico collaboration)	Non-systematic	Infectious	Laboratory	Microorganism	Aerosols, direct contact, percutaneous	Injuries	Yes(lessons learned)
Schlimgen_2016	USA	Non-systematic	Not infectious	Laboratory (lentiviral vector facilities)	Lentiviral vector exposures	Not detailed	Oncogenic	Yes (antiretroviral drugs, regulation)

Table 4
Studies focused on agriculture/animal, vegetable workers

Study_ID	Nationality of the first author	Review types	Infectious/ Non-infectious	Activity sectors/ populations	Hazards	Modes of transmission	Health outcomes	Prevention guidelines (yes/no)
Agunos_2016	Canada	Systematic	Infectious and non-infectious	Poultry exposed occupations	All pathogens (including all HxNx viruses, Erysipelothrix sp bacteria, MRSA, Aspergillus sp fungi and allergens)	Aerosols, direct contact	Infection, allergic response, MRSA carriage	Yes (list of preventive measures)
Basinas_2015	Denmark (with The Netherlands)	Non-systematic	Non-infectious	Livestock farmers	Organic dust, endotoxins	Aerosols	Not investigated	No
Chamba_2016	Mozambique	Non-systematic	Non-infectious	Wood processing industry	Wood dust	Aerosols	Asthma, respiratory symptoms	Yes, some information on potential preventive measures
Cole_2000	USA	Non-systematic	Infectious and non-infectious	Pig industry	Zoonotic pathogens and antibiotic-resistant bacteria carriage and endotoxins, dust, airborne bacteria	Aerosols, direct contact	Infection and respiratory symptoms	No
Dadar_2022	Iran	Systematic	Infectious	Workers in contact with livestock, wildlife and pets	Brucella sp	Aerosols and direct contact	Brucellosis	No
Davidson_2018	Australia	Non-systematic	Non-infectious	Cannabis production and handling	Organic dust, bioaerosols, pollen, plant allergens	Aerosol, direct contact	Respiratory symptoms, allergy, byssinosis	Yes, Australian OEL
Déléry_2009	France	Non-systematic	Non-infectious	Agriculture, wood and waste industries	Endotoxins	Aerosols	Respiratory symptoms	Yes, report on current recommendations (OEL) from different countries
Dias_2022	Portugal	Systematic	Non-infectious	Sawmills	Wood dust, bioaerosols	Aerosols	Allergy, respiratory symptoms	No
Dignard_2019	USA	Non-systematic	Infectious and non-infectious	Animal workers	Zoonotic pathogens, antibiotic-resistant bacteria carriage	Aerosols, direct contact	Infection	No
Donham_1985	USA	Non-systematic	Infectious	Agriculture	Zoonotic agents	Aerosols, direct contact	Zoonoses, respiratory symptoms	No
Dutkiewicz_2011	Poland	Non-systematic	Infectious and non-infectious	Mainly outdoor workers (agriculture, forestry)	Zoonotic agents, bioaerosols	Aerosols, direct contact	Zoonoses, respiratory symptoms	No
Fontana_2017	Italy	Systematic	Non-infectious	Agriculture	Organic dust, endotoxins	Aerosols	COPD	No
Gessain_2008	France	Non-systematic	Infectious	Animal workers: Hunters, laboratory workers, zoo, veterinarians	Simian foamy virus	Direct contact, percutaneous	Infection	No
Lebouquin_2011	France	Non-systematic	Infectious and non-infectious	Poultry industry	Zoonotic agents and organic dust, bioaerosols, endotoxins	Aerosols and direct contact	Zoonoses, respiratory symptoms	Yes
Magri_2021	Brazil	Systematic	Infectious and non-infectious	Poultry industry	Zoonotic pathogens, organic dust	Aerosols, direct contact	Infections and respiratory symptoms	No

May_2012	USA	Non-systematic	Non-infectious	Large animal farms	Bioaerosol, organic dust	Aerosols	Respiratory symptoms	No
Omland_2002	Denmark	Non-systematic	Non-infectious	Livestock farmers	Bioaerosols, organic dust, endotoxins	Aerosols	Respiratory symptoms, allergy, asthma	No
Pereira_2020	Brazil	Systematic	Infectious	Rural, abattoir (butchers), veterinarians, laboratory workers and hunters	Brucella sp	Direct contact with infected animals or contaminated material	Brucellosis	No
Reynolds_2013	USA (with Australia, Denmark, Sweden)	Systematic	Non-infectious	Dairy workers	Bioaerosols, organic dust	Aerosols	Respiratory symptoms,	No
Ricco_2021	Italy	Systematic	Infectious	Agriculture and forestry workers	Hantavirus	Aerosols	Infection	No
Richard_2015	Switzerland	Non-systematic	Infectious	Forestry workers	Borrelia sp, Francisella tulerensis, Leptospira interrogans	Aerosols, vector-borne, direct contact	Lyme disease, tularemia and leptospirosis	Yes (biosafety)
Samadi_2013	The Netherlands (with Iran)	Non-systematic	Infectious and non-infectious	Veterinarians	Zoonotic agents, bioaerosols and allergens	Aerosols, direct contact, percutaneous	Zoonosis, respiratory symptoms, allergy	No
Sigsgaard_2020	Denmark (with Germany, The Netherlands)	Non-systematic	Non-infectious	Livestock farmers	Bioaerosols, organic dust	Aerosols	Respiratory symptoms, asthma, rhinitis	Yes, citing literature reporting engineering and production parameters affecting farmers' exposure to bioaerosols
Tsapko_2011	Ukraine (with Poland)	Non-systematic	Non-infectious	Agriculture	Bioaerosols, organic dust	Aerosols	Not mentioned	No
Wangia_2019	USA	Non-systematic	Non-infectious	Farming, grain milling, animal husbandry and textile production	Aflatoxin	Aerosols, direct contact	Cancer	No
Wilhelm_2011	Canada	Systematic	Infectious	Workers in contact with pigs	Hepatitis E virus	Percutaneous	Hepatitis	No
Youssef_2021	UK	Systematic	Infectious	Livestock farmers	Zoonotic agents	Not detailed	Zoonosis	No
Burdzik_2012	South Africa	Non-systematic	Non-infectious	Food and seafood processing workers	Allergic proteins, irritant proteins	Direct contact with food	Contact dermatitis	No
Jeebhay_2010	South Africa (with Canada)	Non-systematic	Non-infectious	Seafood industry	Respiratory symptoms, asthma	Aerosols	Respiratory symptoms, asthma	Yes
Lai_2013	USA	Non-systematic	Non-infectious	Textile workers	Dust, endotoxins	Aerosols	Asthma and COPD	No
Nafees_2016	Pakistan	Systematic	Non-infectious	Textile workers	Cotton dust, endotoxins	Aerosols	Byssinosis	Yes (effectiveness of prevention)
Nafees_2022	Pakistan (with UK, Italy)	Systematic	Non-infectious	Textile workers	Cotton dust, endotoxins	Aerosols	Byssinosis	No

Table 5
Studies focused on waste sectors

Study_ID	Nationality of the first author	Review type	Infectious/Non-infectious	Activity sectors/ populations	Hazards	Health outcomes	Prevention guidelines (yes/no)	Modes of transmission
Anzivino-Viricel_2012	France	Systematic	Infectious and non-infectious	Waste	Mainly non-infectious hazards	Irritation, respiratory symptoms, gastrointestinal symptoms	No	Aerosols, direct contact
Corrao_2013	Italy	Systematic	Infectious	Waste	Hepatitis B virus	Hepatitis	No	Percutaneous exposure to body fluids
Han_2021	China	Non-systematic	Infectious and non-infectious	Waste	Bioaerosols, antimicrobial-resistant gene	Infections, respiratory symptoms, skin symptoms	No	Aerosols, direct contact
Madsen_2021	Europe	Non-systematic	Infectious and non-infectious	Waste	Biological hazards	Infection, respiratory symptoms, toxic effects, gastrointestinal effects	Yes (Table 3, appendix)	Aerosols, direct contact
Muzaini_2021	Malaysia	Systematic	Not infectious	Waste	Bioaerosols, organic dust, endotoxins	Respiratory symptoms	No	Aerosols
Oza_2022	USA (with Switzerland)	Systematic	Infectious and non-infectious	Waste	Infectious agents	Bacterial and parasitological infections, respiratory symptoms,	No	Aerosols, direct contact
Poole_2017	UK	Systematic	Infectious and non-infectious	Waste	Infectious agents and bioaerosols	Infections, respiratory and skin symptoms	No	Aerosols, direct contact, percutaneous
Van_Kampen_2020	Germany	Systematic	Infectious and non-infectious	Waste	Infectious agents and dust (bioaerosols)	Infection, respiratory symptoms	No	Aerosols, direct contact, percutaneous
Pearson_2015	UK	Systematic	Infectious and non-infectious	Composting facilities	Bioaerosols, organic dust, Aspergillus fumigatus	Respiratory symptoms, infection, allergy	No	Aerosols, direct contact
Robertson_2019	UK	Systematic	Not infectious	Waste	Bioaerosols, organic dust	Respiratory symptoms, gastrointestinal symptoms	No	Aerosols

and in the forestry sector, the maximum averages were 7,070 EU/m^3. The most frequent health effects associated with occupational exposure to organic dust are respiratory symptoms. However, the dose–response relationship between levels of exposure and health outcomes is difficult to establish since exposure characterization suffers from a lack of standard protocols for bioaerosol sampling and analysis. Thus, there are no occupational exposure limits available to ensure workplace safety. Several countries provide recommendations, but there is no international consensus. Only the Netherlands has proposed an occupational exposure limit for endotoxins, although without defining a methodology for sampling and analysis. Forestry workers and hunters are potentially exposed to zoonotic agents from wild animals, whereas animal farmers, workers in the animal food industry, veterinarians, and abattoirs workers are exposed not only to zoonotic agents from livestock but also the risk of being colonized by antimicrobial-resistant bacteria transmitted from animals. This last issue is a rather 'new' investigative research area and has, therefore, not yet been fully taken into account in review papers. In the waste sectors, in addition to exposure to non-infectious agents, there is a great risk of workers coming into contact with human pathogens [13,64,67,70,74].

Different limits should be mentioned. First, it is not a systematic review but a systematized review, since our goal was to provide an overview of populations and risks, without answering any single precise question [7]. Second, relevant original studies, could not be included, if they were not referenced as review papers or guidelines not focusing on biological risk. Furthermore, the low proportion of systematic reviews, with very different focuses (from the effectiveness of prevention methods to the jobs exposed), did not enable us to assess the quality of their evidence, their effect size and did not allow to perform sensitivity analyses. Therefore, to avoid confusion, the term 'umbrella review' was not used. For instance, exposures to the many different biological hazards described were measured using diverse, non-comparable methods (sampling and analysis). Moreover, descriptions of the methods used to collect and/or quantify viruses or protein allergens were very scarce, as these methods were only in the development stage. Finally, dose–response relationship between exposure to biological hazards and their associated health effects (dose-response curve) were rarely investigated.

Furthermore, our investigation focused on published reviews on biological hazards. Publication bias is probable since we only chose reviews pertinent to the overview's aim. Indeed, many worthwhile original studies were not included. As we focused our attention on review papers alone, we may have missed new or emerging issues that have not yet been targeted by reviews of the literature. It is probable that some relevant studies on very specific aspects of biological hazards have been missed due to their novelty: for instance, as we mentioned earlier, healthcare workers' fitness to work [8], states of the arts without reviews [90] or with no relationship with health issues [91], the proportion of workers exposed to COVID-19 and job-exposure matrices [9,10], exposure to antimicrobial-resistant bacteria, exposure to some biological risks and effects on mental health [11], and reviews or guidelines on general preventive, health, and safety issues that included biological hazards were not included in this overview [12]. We also focused only on publications in English and French, but we found articles concerning a great diversity of countries and covering a long period.

In conclusion, the biological hazards present in working environments are very significant in many occupational activities, involving different modes of exposure and different health outcomes. Further studies are necessary to quantify these risks and thus establish occupational exposure limits, to help implement prevention measures that can be applied to all workplaces and to combat all hazards to human health, including new emerging ones.

Conflicts of interest

The authors declare no conflicts of interest.

Disclamer

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the aforementioned institutions.

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Appendix A. Supplementary data

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