






Review

Hidden Hazards: A Literature Review on Occupational Exposure to Fungi and Mycotoxins in the Coffee Industry

Filipe da Silva de Oliveira ^{1,*}, Ednilton Tavares de Andrade ¹, Carla Viegas ²,
Jéssica Raquel Sales Carvalho de Souza ³, Giovanni Francisco Rabelo ⁴ and Susana Viegas ⁵

- ¹ Department of Agricultural Engineering, School of Engineering, Universidade Federal de Lavras–UFLA, Lavras 37203-202, MG, Brazil; ednilton@ufla.br
- ² H&TRC–Health & Technology Research Center, ESTeSL–Escola Superior de Tecnologia e Saúde, Instituto Politécnico de Lisboa, 1990-096 Lisboa, Portugal; carla.viegas@estesl.ipl.pt
- ³ Department of Food Science, School of Agricultural Sciences, Universidade Federal de Lavras–UFLA, Lavras 37203-202, MG, Brazil; jessica.souza9@estudante.ufla.br
- ⁴ Department of Control and Automation Engineering, School of Engineering, Universidade Federal de Lavras–UFLA, Lavras 37203-202, MG, Brazil; rabelo@ufla.br
- ⁵ Public Health Research Centre, Comprehensive Health Research Center, CHRC, NOVA National School of Public Health, NOVA University Lisbon, 1990-096 Lisbon, Portugal; susana.viegas@ensp.unl.pt
- * Correspondence: filipe.oliveira2@ufla.br

Abstract: Several studies have reported the incidence of fungi and mycotoxins in coffee beans; however, there are few reports related to occupational exposure to these agents at coffee dry milling industries. The aim of this review was to identify and to analyze studies assessing occupational exposure to fungi and mycotoxins in coffee industries. Therefore, a systematic literature search was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology and focusing on the assessment of occupational exposure to fungi and mycotoxins in the coffee industry. In these papers, different environmental matrices were considered in evaluating occupational exposure, but the most used matrix was airborne dust (four of the five studies). Airborne fungi were sampled using active (four of the five studies) and passive sampling. Only the most recent of the studies (2022) identified microorganisms by their genera and species, and only two groups of mycotoxins were analyzed in the studies considered, namely, Ochratoxin A and Aflatoxins. None of the studies reported data on both fungi and mycotoxins. The fungal genera identified in these occupational environments included *Cladosporium*, *Paecilomyces*, *Aspergillus*, *Penicillium*, and other genera. Among the mycotoxins, only aflatoxins and ochratoxin A were investigated. Occupational exposure to these biological agents may lead to several health effects. Fungal spores and fragments can cause respiratory diseases such as asthma, allergic rhinitis, bronchitis, and hypersensitivity pneumonitis. Additionally, the mycotoxins studied—particularly Aflatoxins and Ochratoxin A—are associated with serious toxicological effects. Coexposure to both fungi and mycotoxins may enhance health risks and should be carefully considered in occupational risk assessments. Considering the possible effects related to exposure to fungi and mycotoxins and the number of workers involved in this type of industry in the world, more studies should be developed. This is the first review to systematically consolidate data on occupational exposure to both fungi and mycotoxins specifically within the coffee industry, highlighting existing knowledge gaps and the need for targeted risk assessments in coffee-producing settings.

Keywords: post-harvest coffee industries; occupational exposure; fungi; mycotoxins; dust



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1. Introduction

Occupational exposure to airborne biological agents has been reported in the literature at different workplaces [1,2]. Bioaerosols are defined as airborne particles, including fungal spores and hyphae, bacteria, endotoxins, β (1 \rightarrow 3) glucans, mycotoxins, or high-molecular-weight allergens, and organic dusts in general, composed of or derived from biological matter [3].

Coffee is one of the most important beverages in the world [4]. According to the International Coffee Organization [5], the total production by all exporting countries during the 2019/2020 crop year was approximately 9.9 million tons of coffee beans. Brazilian production for that same year was nearly 3.5 million tons, representing more than a third of world production. Also, in that crop year, Brazil exported more than 2.4 million metric tons, which is nearly 70% of its total production [6].

As reported in the General Register of Employed and Unemployed Persons [7], in September 2021, there were 78,106 workers in coffee industries in Brazil, with 60,362 working in general warehouses and 17,744 in grinding and roasting companies. In other words, thousands of Brazilian workers are engaged in tasks involving the handling of coffee beans at different processing stages. Coffee post-harvest processes include steps ranging from washing and separating the fruit; drying, processing, and reprocessing the beans until they are stored; to roasting the beans. Coffee dry milling and storage industries are responsible for grading and classifying coffee beans, improving the type and sensory characteristics of the green coffee beans (GCBs) [8]. Meanwhile, coffee roasting industries are responsible for receiving GCB, roasting, grinding, and packaging. In summary, in a GCB dry milling company, the following processes take place: receiving, cleaning, sorting, selecting, blending, and dispatching. In all these processes, handling GCB ruptures some beans, forming dust [9].

Dry milling is a process that involves receiving, cleaning, hulling, polishing, and sorting the GCB; the hulled beans are sorted by size, density, and color [10]. This process can produce a significant amount of dust to which workers are exposed if adequate risk management measures are not in place; the dust can pose health hazards to workers. The amount of dust produced in a coffee dry milling unit depends on factors such as the type of milling equipment used, the size of the operation, and the condition of the coffee beans being processed. The dust is mainly made up of small particles of dried coffee fruit and other organic material such as fungi and mycotoxins. These dust particles can range in size from very fine particles to larger particles visible to the naked eye [11]. The smaller particles can be inhaled deep into the lungs and potentially reach the alveoli, while the larger particles are trapped in the upper respiratory tract [12].

Several studies in the literature have reported the presence of fungal genera in green coffee beans, including the genera *Aspergillus* [13,14], *Penicillium* [15], and *Fusarium* [16], among others [17,18]. In addition, other authors have confirmed the presence of different mycotoxins in green coffee beans, such as aflatoxins [19,20], ochratoxins [21–23], and others [24,25]. Therefore, since fungi and mycotoxins are commonly found in the GCB, the presence of these agents in the workplace environment where the GCB are handled is foreseeable. However, there are few reports in the literature on occupational exposure to fungi and mycotoxins in the coffee industry.

Exposure to fungi such as *Aspergillus*, *Penicillium*, and *Fusarium* can pose health risks, including respiratory issues and allergic reactions, as these molds are known to produce mycotoxins that may adversely affect human health [26–28]. Mycotoxins are metabolites produced by specific fungal genera, which may cause a diversity of health effects [29]. These compounds can become airborne when attached to spores, fragments, and dust [30]. Therefore, it is of pivotal importance to study occupational exposure to mycotoxins in

settings like the coffee industry, where exposure to organic dust can occur in different tasks such as storage, loading, or handling GCB materials [31].

The objective of this study is to identify the literature available on occupational exposure to fungi and mycotoxins in the coffee processing industry and identify gaps in knowledge and the need for future research.

2. Materials and Methods

2.1. Search Strategy and Inclusion and Exclusion Criteria

This study reports on the data available on occupational exposure to fungi and mycotoxins in post-harvest coffee industries published between 1 January 1991 and 14 April 2025, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [32]. The databases chosen were PubMed, Scopus, and Web of Science, and the keywords used were “occupational exposure” AND “mycotoxins” OR “fungi” AND “coffee”. Searches were carried out in English, and articles that did not meet the inclusion criteria and duplicate articles were excluded from further analysis (Table 1).

Table 1. Inclusion and exclusion criteria in the selected articles.

Inclusion Criteria	Exclusion Criteria
Articles published in the English language	Articles published in other languages
Original scientific articles on the topic	Abstracts of congress, reports, reviews/state-of-the-art articles
Articles related to occupational exposure in the coffee industry	Articles related to other food commodities
Articles related to occupational exposure	Articles dedicated only to coffee bean quality analysis

2.2. Selection of Studies and Data Extraction

Two rounds of article selection were performed by three investigators (FO, JS, and GR). The first round consisted of screening all titles and abstracts. In the second round, the full texts of all potentially relevant studies were reviewed considering the inclusion and exclusion criteria. Potential divergences in the selection of this study were discussed and ultimately resolved by the remaining investigators (SV, CV, and EA). Three investigators (FO, JS, and GR) extracted data, and the other three reviewed that data. The following information was manually extracted: (1) title, (2) country, (3) occupational setting, (4) types of samples considered, (5) sampling methods, (6) analytical methods, (7) results, and (8) main conclusions.

2.3. Quality Assessment

The risk of bias was assessed by two investigators (CV and SV). Within each study, this risk was evaluated across four parameters divided as key criteria (type of samples considered, sampling method, microorganisms detected, and mycotoxins found) and other criteria (incomplete data about the key criteria and conflict of interest). The risk of bias for each criteria was evaluated as “low”, “medium”, “high”, or “not applicable”. The studies for which all the key criteria and most of the other criteria are characterized as “high” were excluded.

3. Results

The flow diagram for the selection of studies is shown in Figure 1. The primary search on the databases yielded 32 papers. This resulted in 19 reports assessed for eligibility, and 14 of them were excluded for not meeting the inclusion criteria. Of the 14 papers excluded,

7 were unrelated to occupational exposure; 4 were not related to the coffee industry; 2 were reviews; and 1 was excluded for not being published in English. Therefore, a total of five papers were included in this review.

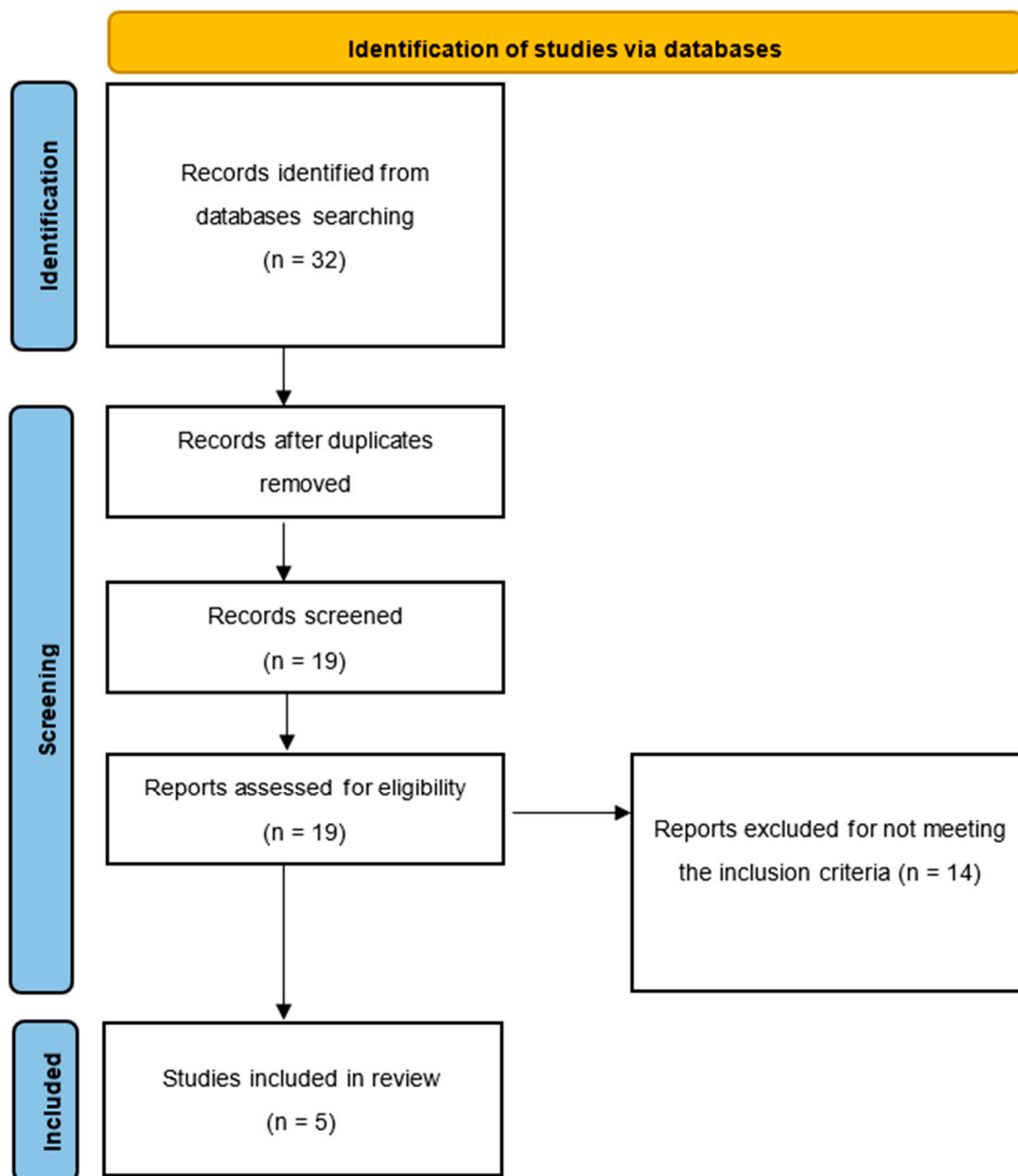


Figure 1. PRISMA methodology for selection of papers.

Analysis of the five papers used in this study (Table 2) included examination of the occupational environment studied, the country where the study was developed, the sampling methods used (including the matrixes used), the analytical methods applied, and the exposure data obtained. None of the papers reported on both fungi and mycotoxins, and three papers used biomonitoring approaches to assess workers' exposure to mycotoxins besides those from settled/airborne dust [33–35].

Table 2. Data obtained from the selected articles.

Title	Study	Firm Sample Location	Occupational Setting	Matrices Analyzed	Sampling Method	Analytical Method		Results		Main Conclusions
						Toxins/ Microorganisms Studied	Laboratory Method	Microorganisms Identified	Mycotoxins Detected	
Microbial Contamination in the Coffee Industry: An Occupational Menace besides a Food Safety Concern?	[36]	Brazil	Coffee dry milling firm	Dust; FRPD; GCB	EDC; settled dust	Fungi; bacteria	Plate incubation, qPCR	<i>Cladosporium</i> ; <i>Paecilomyces</i> ; <i>Aspergillus</i> ; <i>Penicillium</i> ; other fungal genera; Gram-negative bacteria		This study draws attention to the need to consider occupational exposure to mycotoxins in the dry milling stage and other stages, due to high fungal diversity and contamination.
Use of high-performance liquid chromatography to assess airborne mycotoxins	[37]	Spain	Coffee processing	Dust	Filtration	Mycotoxins	HPLC	<u>Green coffee from big bags</u> OTA: <2.0 ng m ⁻³ AFL: <0.06 ng m ⁻³ <u>Big coffee bags on a conveyor belt</u> OTA: <0.4 ng m ⁻³ AFL: <0.01 ng m ⁻³	The authors concluded that the concentration of mycotoxins was lower than the detection limit of the method used. However, the authors emphasize that occupational exposure limits have not been set.	

Table 2. Cont.

Title	Study	Firm Sample Location	Occupational Setting	Matrices Analyzed	Sampling Method	Analytical Method		Results		Main Conclusions
						Toxins/ Microorganisms Studied	Laboratory Method	Microorganisms Identified	Mycotoxins Detected	
Exposure assessment to mycotoxins in workplaces: aflatoxins and ochratoxin A occurrence in airborne dusts and human sera	[33]	Italy	Warehouse: Handling and processing of coffee beans	Dust; serum	Stationary and personal filtration	Mycotoxins	HPLC		Personal OTA: $0.007\text{--}0.066\text{ ng m}^{-3}$ Dust: $0.006\text{--}0.018\text{ ng m}^{-3}$	This study showed a wide range of OTA levels in the samples. This could be related to the distance between the worker and the stocked raw materials and the manual tasks being developed.
External and internal dose in subjects occupationally exposed to ochratoxin A	[34]	Italy	Coffee processing warehouse	Dust; serum	Stationary and personal filtration	Mycotoxin: OTA	HPLC		Airborne OTA: 0.051 ng m^{-2} Serum: 2.41 ng mL^{-1}	OTA represents an occupational hazard, in addition to other mycotoxins potentially present in the workplace.

Table 2. Cont.

Title	Study	Firm Sample Location	Occupational Setting	Matrices Analyzed	Sampling Method	Analytical Method		Results		Main Conclusions
						Toxins/ Microorganisms Studied	Laboratory Method	Microorganisms Identified	Mycotoxins Detected	
Factors relating to the development of respiratory symptoms in coffee process workers	[35]	England	Coffee processing firm: unloading; tipping; roasting	Dust; serum	Impaction	Total fungi; total bacteria	Culture-based methods	<u>Bacteria</u> Container unloading: 4.12×10^{-3} CFU m ⁻³ Tipping: 8.50×10^{-3} CFU Roasting: 1.90×10^{-3} CFU m ⁻³ <u>Fungi</u> Container unloading: 8.14×10^{-3} CFU m ⁻³ Tipping: 3.40×10^{-3} CFU m ⁻³ Roasting: 5.65×10^{-3} CFU m ⁻³		The collected data show that different work areas resulted in different mean concentrations of airborne dust and microorganisms. The study also suggests that respiratory symptoms are work-related.

AFL: aflatoxins; CFU: colony-forming unit; EDC: electrostatic dust cloth; FRPD: filtering respiratory protective devices; GCB: green coffee bean; HPLC: high-pressure liquid chromatography; OTA: ochratoxin A; and qPCR: quantitative polymerase chain reaction.

Considering the locations of the firms of the five papers selected for this review, two are in Italy [33,34], one in Brazil [36], one in Spain [37], and one in the United Kingdom [35]. Regarding the sources of contamination in the occupational settings, four of the five papers studied GCB dust [33–35,37], and one of the five papers studied both GCB and roasted coffee bean dust within the same company [35]. Concerning the location of the industries, four [33–35,37] of the five locations are in Europe; only one study [36] assessed industries in a producer country. Concerning the origin of the samples used in the studies, four papers [33,34,36,37] specified the origin of the GCB as Brazil and one paper indicated Africa, South East Asia, and Central and South America [35].

While most studies [33–35,37] collected airborne dust and biological samples (workers' sera), one [36] collected only environmental samples (EDC, settled dust, GCB, and FRPD). As for the analytical methods employed, three of the five papers studied the presence of mycotoxins in dust [33,34,37] and reported the use of HPLC for the sample analysis. Among these three papers, one analyzed different mycotoxins, namely, aflatoxin B1, aflatoxin B2, aflatoxin G1, aflatoxin G2, and ochratoxin A [33], while the other two papers studied only one mycotoxin–ochratoxin A [33,34]. One study assessed only microorganisms present in dust but did not distinguish them by species or genera [35]. Another [36] reported the presence of several fungal genera present at the coffee dry milling industries from Brazil.

4. Discussion

European countries are mainly engaged in processing/handling coffee beans from various regions, such as Brazil, as they are not significant coffee producers. The only tasks studied in the papers selected are the storing and the roasting of the beans [33–37]. Therefore, research is lacking not only on the exposure that occurs during those tasks, but also on occupational exposure to fungi and mycotoxins in countries that produce coffee beans, especially in industries with a considerable amount of coffee bean movement, e.g., in dry milling industries. Although the literature is limited regarding occupational exposure to fungi and mycotoxins in coffee industries, there is evidence of the presence of fungal and mycotoxin contamination in GCBs from all over the world, such as from Africa [13,16,25], America [15,21], and Asia [14,20,23].

Airborne fungal particles found in occupational environments consist of spores, mycelium fragments, and debris present as single particles or complex aggregates [38]. In addition, their incidence depends on the natural selection that occurs in these very complex microbiological communities; several parameters are involved. From a worker exposure and health effect perspective, it is important to characterize microbial contamination in occupational environments. It is due to a vast number of microbial species present in the air [39]. In that case, some of the flour provides essential nutrients favorable to the growth of fungi and bacteria. Coffee industries should likewise be assessed in order to better understand exposure, identify the most suitable risk management measures to prevent health effects, and understand how much of the airborne exposure to mycotoxins is due to the contamination present in the handled material, in this case, GCB [40–42].

Many processes conducted in the coffee supply chain directly affect coffee microbiota and mycotoxins, such as ripening, harvesting, drying, roasting, and brewing methods. According to one of the analyzed papers [32], the ochratoxin concentrations measured were lower than the detection limits of the methods commonly used. However, it is noteworthy that the raw material used by the authors in that study came from Brazil, where the coffee beans were previously milled before export. Thus, the concentrations might represent occupational exposure at Brazilian companies where the GCB are handled and processed after harvesting (Figure 2). In fact, the mycotoxin levels tend to decrease at the end of the coffee supply chain. That is illustrated in a paper studying the effect of different roasting

and brewing methods on mycotoxins. The authors reported that both roasting and brewing might reduce the presence of ochratoxins and aflatoxin A, depending on the roasting level and the brewing method used [40].

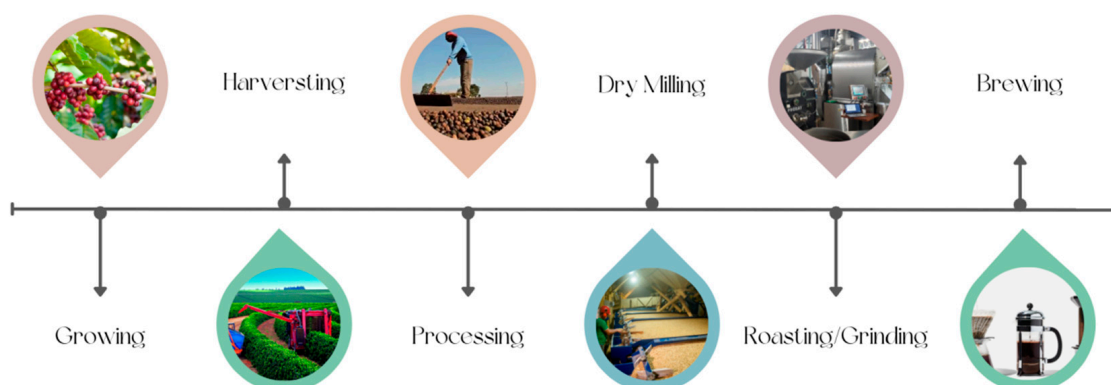


Figure 2. Schematic representation of the coffee supply chain.

Several approaches are available to assess occupational exposure to mycotoxins in workplace settings, such as biomonitoring [41–45] and environmental monitoring [46,47]. Different methods were applied to collect data on mycotoxin exposure in the studies selected [33–37], and the analytical methods used by the authors for measuring occupational exposure through environmental and biological monitoring gave precise and accurate results.

Electrostatic dust cloths (EDCs) have recently been used in dust sample collections to collect airborne materials in different occupational environments [47,48], and they have been used to detect fungal genera in specific indoor environments [49]. Some authors [50] have compared EDCs with the air impaction procedure to measure airborne fungi, and they concluded that EDCs provide a more precise estimation of fungal exposure compared to a single air impaction procedure. This is because EDCs are not only much less tedious and time consuming to use than other airborne dust collection procedures [51] but also make for a longer collection time, and, because of that, they better represent exposure levels. Settled dust has also been used as a matrix, and this procedure involves collecting dust that has settled at different places in the workplace environment [52,53]; it has been widely used in various occupational environments [39,54–56]. In this case as well, the exposure window considered is wider compared to single air impaction. The type of task developed also affects the levels of workers' exposure to fungi and mycotoxins. The papers analyzed (Table 2) indicate that studying each workplace and task separately is of critical importance. The authors concluded that the warehouse was the dustiest among the areas evaluated in the factory. They came to the conclusion that there was a higher concentration of xerotolerant fungi at the unloading area than any other area in the study [35]. A paper published by came to the same conclusion: the dustiness of the tasks is an important determinant of fungal and mycotoxin exposure. This is due to the high intensity of coffee bean handling during the process, e.g., in mechanical sieving [31]. Differences in exposure to fungal and bacterial species have also recently been quantified in different tasks developed in a cucumber greenhouse [57]. Therefore, in order to better understand variations in occupational exposure to airborne fungi and mycotoxins in a coffee warehouse, tasks that include the manual handling of coffee beans should be carefully evaluated, tasks such as grain reception, stone picking, bean pre-cleaning, the use of densiometric tables, filling containers, and dispatch. Such evaluation will allow identification of which tasks bring about higher exposure to the different agents. This,

in turn, will provide better understanding of the risk management measures to apply to mitigate exposure to the different agents present.

Coexposure to multiple mycotoxins is a common feature in workplace environments [31,48,58]. Ochratoxin A has been indicated as an occupational hazard, along with other mycotoxins potentially present in occupational settings of loading, storing, and unloading the jute bags containing the GCB [34]. Even though the available data in the literature only assess one or two groups of mycotoxins (mainly aflatoxins and OTA) in coffee industries, coexposure to other mycotoxins is very likely to occur in these industries since multiple mycotoxin contaminations of GCB have been reported [22,25]. Therefore, it would be more fitting to choose analytical methods that are able to measure multiple mycotoxins in samples collected from these occupational environments [58]. *Aspergillus* species are widely distributed in nature and are commonly found in soil, decaying organic matter, seeds, and grains [59]. It is frequently present in the soil where coffee trees are cultivated [60] and may be introduced into processing facilities through handling and post-harvest operations.

Several species also occur in occupational environments, with some recognized as opportunistic pathogens [61]. *Aspergillus* spp. is considered the leading cause of mold-related infections in humans, capable of triggering serious health conditions in both immunocompetent and immunocompromised individuals.

Aspergillosis, the infection caused by *Aspergillus* species, can affect both humans and animals. Symptoms range from respiratory illnesses and allergic reactions to invasive forms of the disease, which may lead to severe complications in the lungs, brain, and kidneys [62].

Ochratoxin A (OTA) is a known nephrotoxin and a potential carcinogen. It has been directly associated with the development of tumors in the human urinary tract, although the International Agency for Research on Cancer (IARC) currently classifies it as a possible human carcinogen. In addition, OTA has been linked to a range of other health conditions [63]. Aflatoxins are highly toxic secondary metabolites known for their teratogenic, mutagenic, and carcinogenic properties and have been classified as Group 1 carcinogens by the IARC [64].

This review has some limitations due to the search criteria. The search was restricted to specific databases, keywords, and English-language publications, which may have excluded relevant studies, particularly from coffee-producing regions. Methodological variability among the selected studies—such as differences in sampling strategies, analytical techniques, and exposure metrics—limited comparability and precluded quantitative synthesis. Additionally, most studies focused on isolated agents, without addressing coexposure scenarios commonly found in real occupational environments.

Future studies should prioritize standardized methodologies for environmental and biological monitoring to enhance comparability across occupational settings. Research in coffee-producing countries is particularly needed to assess exposure in contexts with high processing volumes and distinct workplace practices. Moreover, potential variations in raw material contamination should be considered, as they may significantly influence the levels of occupational exposure.

5. Conclusions

In general, our findings indicate a lack of published studies analyzing occupational exposure to fungi and mycotoxins in the coffee processing industry. The published research suggests the potential for high exposure to organic dust and its constituents in the coffee industry. According to the available literature, *Cladosporium*, *Paecilomyces*, *Aspergillus*, *Penicillium*, and other genera were commonly found at coffee industries. Regarding the information about mycotoxins, only aflatoxins and ochratoxin A were studied. Therefore,

more studies should be conducted in coffee industries to better understand the hazards present in these workplaces and the related health risks. The importance of considering coexposure to several mycotoxins and fungi species and the impact this might represent for workers' health were also highlighted. Considering that data from companies outside the European continent are limited, studies should be conducted at coffee industries in coffee-producing and processing countries, such as Brazil, which is the main producer and exporter in the world.

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