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Prevalence of airborne fungi in Brazil and correlations with respiratory diseases and fungal infections

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Abstract *Airborne fungi are dispersed through the air. The aim of this study was to determine the prevalence of airborne fungi in Brazil and understand the relationship between fungal growth and respiratory diseases and infections. We conducted an integrative literature review of studies conducted in Brazil based on searches of the PubMed, MEDLINE-BIREME, SciELO, and LILACS databases for full-text articles published between 2000 and 2022. The searches returned 147 studies, of which only 25 met the inclusion criteria. The most prevalent genera of airborne fungi in Brazil are Aspergillus, Penicillium, Cladosporium, Curvularia, and Fusarium. The studies were conducted in the states of Maranhão, Ceará, Piauí, Sergipe, Mato Grosso, Pernambuco, Rio Grande do Sul, Santa Catarina, Rio de Janeiro, São Paulo, and Minas Gerais. The findings also show the relationship between fungi and meteorological factors and seasonality, the sensitivity of atopic individuals to fungi, and the main nosocomial mycoses reported in the literature. This work demonstrates the importance of maintaining good microbiological air quality to prevent potential airborne diseases.*

Key words *Fungi, Air microbiology, Brazil*

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Introduction

Fungi are ubiquitous heterotrophic eukaryotic microorganisms. They are widespread in the air, soil, oceans, deserts, glaciers, plants, humans, animals, and even insects. They have a chitin cell wall and cell organizations range from unicellular to highly complex filaments[1,2]. Fungi are highly diverse, playing an important role in natural cycles, and fungal metabolites have great biotechnological potential, being exploited to acquire bioproducts such as antibiotics, vitamins, and enzymes used in clinical research[3].

Airborne or anemophilous fungi are classified into different genera and species and have spores that remain dry and hydrophobic due to cysteine-rich proteins on their surface[4]. Air dispersal requires the presence of propagules, whose dispersal is influenced by temperature, air humidity, volumetric precipitation, atmospheric pressure, and wind speed, as well as vegetation and pollution[5,6].

Widespread airborne fungal microbiota are associated with adverse health effects[7]. The inhalation of fungal spores can cause allergic respiratory diseases such as asthma, rhinitis, and sinusitis[8]. The prevalence of fungi-induced allergic respiratory diseases was estimated to be between 20 and 30% among atopic patients and 6% in the general population[9]. *Alternaria* sp., *Penicillium* sp., *Aspergillus* sp., and *Cladosporium* sp. are among the genera most commonly associated with hypersensitivity[10].

The diversity of airborne fungal spores varies depending on location (indoor or outdoor), geographic region, and season [10]. Fungal growth is favored by high temperatures and relative humidity, with these conditions triggering greater sporulation and, consequently, a rise in allergic respiratory symptoms[6,11].

In general, levels of fungal microbiota in the air in indoor environments is a reflection of the diversity of fungi in the outdoor environment and airborne species are the most frequently observed contaminants in climatized environments[12]. Poor air quality in enclosed spaces can lead to short- and long-term infections and increase the risk of occupational diseases. Even non-pathogenic fungi pose a risk of causing mycotoxicosis and ear and nail infections[13]. Once introduced into enclosed spaces, spores find suitable substrates to colonize and multiply, presenting a potential occupational *biological hazard*[8,14].

Fungal contamination in hospital environments poses a risk of hospital infection15. More well-known complications caused by fungal infections include invasive pulmonary aspergillosis, allergic fungal sinusitis, otomycosis, and mycotoxin-induced severe toxic reactions, which can lead to death in immunocompromised patients[9].

The World Health Organization (WHO) highlights the rising global health threat of invasive fungal diseases, emphasizing diagnosis and treatment challenges and reinforcing concerns with their resistance to currently available antifungal agents[16]. The coronavirus disease (COVID-19) pandemic raised the alert over the incidence of fungal infection comorbidities, with aspergillosis, mucormycosis, and candidemia gaining prominence in the literature[17].

According to National Health Surveillance Agency (ANVISA) Resolution 9 (January 2003), microbiological contamination is a reference parameter for air quality in indoor climatized environments. The resolution sets a contamination limit of 750 CFU/m3 (where CFU is colony forming units) and an indoor/outdoor (I/O) fungi quantity ratio of ≤ 1.5[18].

The aim of this study was to determine the prevalence of airborne fungi in the country, demonstrate the relationship between fungal allergens and respiratory allergies, and understand the relationship between airborne fungi with pathogenic potential and the occurrence of infection.

This work is justified by the need to update knowledge and data on the prevalence of airborne fungal microbiota in Brazil. Integrative reviews of the prevalence of airborne fungi and the human health impacts of these microorganisms have yet to be undertaken in Brazil. The data generated by this study constitute a source of information on air quality, microbial contamination, and airborne disease prevention.

Methods

We conducted an integrative review of the literature involving the following stages: formulation of the guiding question; definition of criteria for article selection; database search; data collection, analysis, and interpretation; and discussion of results. The guiding question was as follows: "What are the main airborne fungi found in Brazil and their correlation with respiratory diseases and fungal infections?".

Searches were performed of the following databases between February 2021 and December

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2022: PubMed; Medical Literature Analysis and Retrieval System Online (MEDLINE), accessed using the Regional Library of Medicine (BIREME) interface; Scientific Electronic Library Online (SciELO); and Latin American and the Caribbean Literature on Health Sciences (LILACS). The review involved the following stages.

First, we performed database searches for studies relating to the topic that met the inclusion and exclusion criteria. The Health Sciences Descriptors (DeCs) "*fungos*", "*anemófilos*", and "*Brasil*" were used together with the corresponding Medical Subject Headings (MeSH) in English, "fungi", "airborne", and "Brazil". The inclusion criteria were full-text Brazilian articles available online written in English or Portuguese published in national and international journals between 2000 and 2022. Articles that did not address the guiding question, were unrelated to the study topic, and duplicate papers were excluded.

The second stage consisted of data collection and exportation of references to Rayyan QCRI, a reference selection platform that helps remove duplicates and facilitates the title and abstract screening process. The aim of this stage was to identify articles for full-text screening. Exploratory reading was performed, consisting of rapid reading of the selected articles to ascertain whether the studies met the study requirements. Selective reading was then performed, consisting of a more in-depth analysis of the selected articles.

The third stage consisted of the analysis and interpretation of the study results. The articles were catalogued in a table using the following categories: article title, objectives, and main results. The aim of this stage was to organize the content of the articles to obtain responses to the guiding question.

The fourth stage was the discussion of the results, in which the content of the selected studies is analyzed and discussed drawing on the frame of reference.

Results

The searches returned 147 studies, 122 of which were excluded because they were duplicates, were not related to the study topic, or did not meet the eligibility criteria, resulting in a final review sample of 25 studies (Figure 1).

For the search of LILACS, a combination of the keywords "*fungi*", "*anemófilos*" and "*Brasil*" were used together with the Boolean operator "AND". For the MEDLINE-BIREME search, the term "*microbiologia do ar*" (air microbiology) was used. The searches yielded 15 and 30 articles, respectively.

For the searches of PubMed and SciELO, the terms "fungi", "airborne", and "Brazil" were used together with the Boolean operator "AND", resulting in 86 and 16 articles, respectively.

The studies were categorized in a table containing the following headings: article title, objectives, and main results (Chart 1).

Of the 25 articles reviewed by this study, six were conducted in the South, seven in the Southeast, one in the North, nine in the Northeast, and two in the Midwest (Figure 2). The studies show that Brazil has a high diversity of airborne fungal microbiota and that the diversity of composition varies according to region. The following genera had a high incidence across regions: *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., *Fusarium* sp., *Curvularia* sp., and *Alternaria* sp.

While the findings show that the hot climate of the tropics is conducive to the occurrence of airborne fungi, the role relative humidity plays in the dispersal process and fungal growth is not clear. The results suggest that humidity facilitates the concentration of fungi, but excess humidity can have a negative effect on the transport of fungal spores. In contrast, sunlight and wind increase the atmospheric dispersal of spores.

The works compiled in this review make an important contribution to existing knowledge of fungal allergies. Exposure to fungal spores increases the risk of asthma or rhinitis attacks in atopic patients. The studies assessed by this review identified a diverse range of species of fungal aeroallergens associated with respiratory diseases. Besides allergic reactions, the literature has documented fungal infections caused by airborne fungi. Fungi with pathogenic potential from the genera *Aspergillus* sp., *Penicillium* sp., and *Cladosporium* sp. were found in controlled hospital environments. Hospital-acquired infections caused by fungi have a high impact on patient morbidity and mortality, meaning that effective aerobiological monitoring of these settings is essential to prevent infection.

Discussion

The discussion of the selected articles is divided into three categories: a) prevalence of airborne fungi in Brazil; b) Airborne fungi and implications for allergic reactions; and c) Airborne fungi and implications for fungal infections.

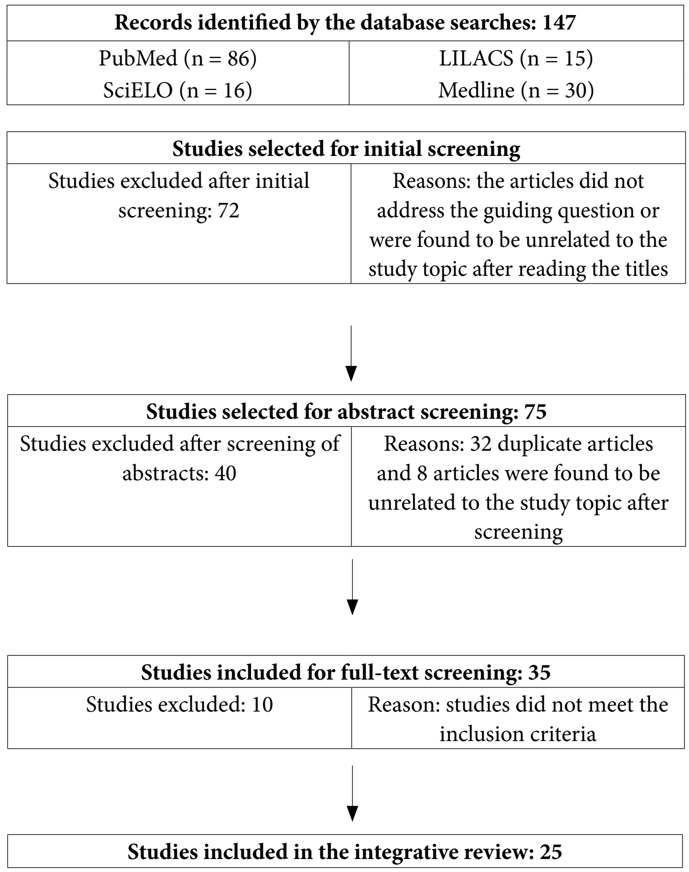

Figure 1. Flowchart of the article selection process.

Source: Authors.

Prevalence of airborne fungi in Brazil

Airborne fungi are abundant ubiquitous organisms and have the capacity to produce spores or fungal propagules[19]. Spores are ubiquitous and essential structures for fungal dispersal and colonization. Their concentration, aerodynamic diameter, and taxonomic compositions vary considerably and are greatly influenced by environmental factors such as temperature, relative humidity, and season[14,20].

According to the findings of the studies, tropical climates are conducive to fungal growth, with the climate in countries like Brazil resulting in the release of large numbers of spores and generating high concentrations of fungi in the atmosphere[14,21]. With suitable levels of oxygen, temperature, and humidity, airborne fungi produce metabolites that favor their development in available substrates[12]. Current knowledge of the transport of bioaerosols shows that meteorological factors influence the spread of fungal spores, with higher temperatures, sunlight, and wind enhancing airborne dispersal[22]. A positive correlation was found between humidity and fungi quantities, in contrast to older studies pointing to higher spore counts in dry and hot seasons[21,23].

There is no consensus in the literature regarding seasonality and spore dispersal. A study in Porto Alegre reported higher spore counts in the summer than in the autumn, while research in Fortaleza demonstrated that the concentration of spores was higher in slightly lower temperatures in January and June[20,21]. A study evaluating the air quality of ICUs in the South found a pronounced variation in fungi counts between seasons, with the autumn months showing the highest prevalence rates[23]. There are stark differences in cli-

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Chart 1. Categorization of study information.

Title	Objectives	Main results
Airborne fungi in the region of Cubatão, São Paulo State, Brazil	To compare the diversity of airborne fungi between a region highly affected by air pollution and region less affected by the air pollution	Seventeen common, 12 rare, and one constant fungal species were found in the region highly affected by air pollution, compared to 19, 10, and two, respectively, in the region less affected by the air pollution.
Airborne fungi in the city of Porto Alegre, Rio Grande do Sul, Brazil	To investigate the prevalence and seasonal variation of airborne fungi in Porto Alegre	The most common fungi were ascospores, *Cladosporium*, *Aspergillus*, and *Penicillium*. More fungal spores were observed during the summer than during the autumn.
Airborne fungi and sensitivity in atopic individuals in Porto Alegre, RS, Brazil	To determine the prevalence of airborne fungi in Porto Alegre and assess sensitivity to allergens in atopic individuals	The most prevalent fungi were C*ladosporium, Aspergillus, Penicillium, Helminthosporium, ascospores*, and *basidiospores*; 15,38% of atopic individuals had sensitivity to airborne fungi.
Airborne fungi isolated in Fortaleza, Ceará, Brazil	To determine the prevalence and seasonal variation of airborne fungi in Fortaleza	The genera A*spergillus, Penicillium, Mycelia sterilia, Fusarium,* and *Alternaria* were found during all months in the year.
Airborne fungi causing respiratory allergy in patients from Fortaleza, Ceará, Brazil	To study the relationship between airborne fungi and respiratory allergies among patients in Fortaleza	All the 10 most prevalent airborne fungi can cause positive skin test reactivity in individuals with respiratory allergies.
Monitoring of airborne fungus and yeast species in a hospital unit	To monitor and characterize airborne filamentous fungi and yeasts in a hospital unit	Thirty-two genera of airborne fungi were recovered from the surgical center and 31from the intensive care units. The most frequently isolated genera were *Cladophialophora sp., Fusarium sp., Penicillium sp., Chrysosporium sp.,* and *Aspergillus sp*.
Fungal microbiota in air conditioners in intensive care units in Teresina, Piauí	To identify airborne fungi in air conditioners in ICUs in Teresina-PI	Eight genera and 33 species of fungi were found. All the species found were pathogenic and can aggravate the condition of hospital patients
Isolation of pathogenic yeasts in the air from hospital environments in the city of Fortaleza, northeast Brazil	To monitor pathogenic yeasts in 2 hospitals in Fortaleza	Critical and semi-critical areas had the same number of yeasts. Four different yeast genera were isolated: *Candida, Rhodotorula, Trichosporon,* and *Saccharomyces*
Indoor and outdoor atmospheric fungal spores in the São Paulo metropolitan area (Brazil): species and numeric concentrations	To estimate the indoor and outdoor concentrations of fungal spores in the Metropolitan Area of Sao Paulo.	*Penicillium sp. and Aspergillus spp.* were the most prevalent species both indoors and outdoors in both seasons
Fungal microbiota in air-conditioning installed in adult and neonatal intensive treatment units and their impact in two university hospitals in the central western region, Mato Grosso, Brazil	To evaluate fungal microbiota in air-conditioning units installed in ICUs in two university hospitals in Mato Grosso	The most frequently detected genera in both hospitals were *Aspergillus sp., Penicillium sp.*, and *Cladosporium sp*.
Trichocomaceae: Biodiversity of Aspergillus sp. and Penicillium sp. residing in libraries	To determine the prevalence of airborne fungi from the genera Aspergillus and Penicillium in libraries	*Aspergillus sp. and Penicillium sp.* were identified in 89.6% and 10.4% of samples. Quantities of both genera were highest in the dry season.
Frequency of airborne fungus in critical areas at a hospital unit in Aracaju, Sergipe, Brazil	To determine the frequency of airborne fungi in four critical areas in a hospital unit.	The most frequent genera were *Aspergillus sp.* (43%), *Penicillum sp*. (12%), *Fusarium sp.* (11%), *Candida sp*. (6%), and *Curvularia sp.* (5%).
Indoor air as a potential determinant of the frequency of invasive aspergillosis in intensive care units	To determine the concentration of airborne fungi in three ICUs in Brazil and correlate fungal burden with the frequency of Aspergillus spp. isolation from clinical samples of patients in these units	More than half of the isolated fungi were *Cladosporium sp. or Penicillium sp.* Fungal contamination of indoor air may influence the frequency of invasive *Aspergillus* in ICU patients.

it continues

Chart 1. Categorization of study information.

Title	Objectives	Main results
Diversity and dynamics of airborne fungi in São Luis, State of Maranhão, Brazil	To identify airborne fungi in São Luis, Maranhão and correlate these genera with the area and season	The most common fungi were A*spergillus Penicillium, Cladosporium, Curvularia* and *Fusarium*. Fungal biological diversity did not show large seasonal variations.
Respiratory allergy to airborne fungi in São Luís, MA: clinical aspects and levels of IgE in a structured asthma program	To analyze the level of specific IgE against airborne fungi in patients with a clinical diagnosis of asthma and rhinitis/sinusitis	Prevalence of seropositivity was 79.7% for *Penicillium sp*., 77.8% for *Neurospora sp*., 77.8% for *Fusarium sp*., and 44.9% for *Aspergillus sp*.
Effect of the implosion and demolition of a hospital building on the concentration of fungi in the air	To evaluate the impact of the demolition of a wing of a hospital in Rio de Janeiro on the concentration of fungi inside and outside the hospital.	The implosion and mechanical demolition of the building resulted in a large increase in the concentration of fungi in the air.
IgE serum concentration against airborne fungi in children with respiratory allergies	To evaluate total and specific E immunoglobulin (IgE) antibody concentrations in children aged 10-14 with allergic respiratory diseases	IgE total serum concentration increased in 97% of the atopic individuals.
Antimicrobial and enzymatic activity of anemophilous fungi in a public university in Brazil	To determine the air quality of an academic center and analyze potential enzymatic and antimicrobial production of isolated fungi	The most common fungal genera were *Aspergillus, Penicillium, Talaromyces, Curvularia,* and Paecilomyces. Isolated fungi have potential for enzymatic and antimicrobial activity.
Airborne fungi in an intensive care unit	To isolate and identify airborne fungi in an ICU in a University Hospital in Pelotas	Seven fungi genera were identified, the most prevalent of which was P*enicillium sp*., followed by *Aspergillus sp., Cladosporium sp., Fusarium sp., Paecelomyces sp., Curvularia sp*., and *Alternaria sp*.
Airborne fungi isolated from different environments of a primary school in the city of Manaus, Amazonas, Brazil	To identify airborne fungi in a primary school and determine the influence of seasonality	The most frequent genera during the dry and rainy seasons were *Aspergillus sp.* (19.21%) and *Cladosporium sp*. (34,8%), respectively.
Air pollution and its impact on the concentration of airborne fungi in the megacity of São Paulo, Brazil	To monitor airborne fungi and bacteria in São Paulo and assess correlations with atmospheric conditions and the concentration of other air pollutants	The number of CFUs increased by approximately 80% during the sampling period in response to environmental changes favored by a truck driver strike.
Study of airborne fungal microbiota in three environments of a University in Santa Catarina	To analyze the presence of airborne fungi in indoor and outdoor environments in a university in the state of Santa Catarina	The most prevalent genera of fungi were *Gliocladium sp., Fusarium sp., Penicillium sp*. and *Cladosporium sp*.
Monitoring of airborne fungi in a library in São José do Rio Preto, São Paulo	To detect the presence of airborne fungi in a library in São José do Rio Preto	The following genera were identified: *Aspergillus sp.* (19 isolated) *Cladosporium sp.* (6 isolated); *Curvularia sp.* and *Trichoderma sp*. (3 of each isolated); *Cunninghamella sp., Penicillium sp*. and *Scopulariopsis sp.* (2 of each isolated); *Beauveria sp.*, *Chaetomium sp., Mucor sp.* and *Nigrospora sp*. (1 of each isolated).
Evaluation of microbiological air parameters and the fungal community involved in the potential risks of biodeterioration in a cultural heritage of humanity, Ouro Preto, Brazil	To investigate air microbiological parameters inside Nossa Senhora da Conceição Church and identify the population of airborne fungi	Two fungal species were detected colonizing artworks: *Cladosporium cladosporioides* and *Aspergillus versicolor*. Air quality monitoring inside the church was in accordance with the standards set out in the legislation in Brazil.
Airborne fungi in Laranjal Beach, Pelotas, Rio Grande do Sul	To identify airborne fungi in Laranjal Beach over a period of one year	The most prevalent airborne fungi were *Cladosporiums sp., Alternaria sp., Penicillium sp., Curvularia sp*., and non-sporulating fungi.

Source: Authors.

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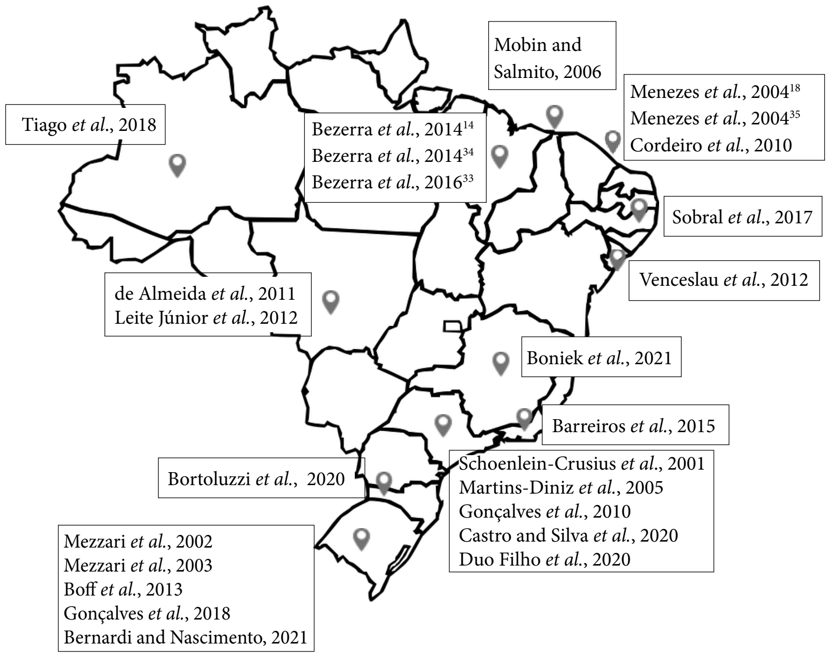

Figure 2. Geographical distribution of the selected studies.

Source: Authors.

mate between the South and Northeast of Brazil, making it difficult to establish a pattern of fungal growth. In 2021, Bernardi and do Nascimento corroborated the results of a study in Manaus showing that certain genera are more common in specific seasons, with *Cladosporium* sp. having higher incidence in the rainy season and *Aspergillus* sp., *Curvularia* sp. and *Penicillium* sp. being more prevalent in the dry season[24,25].

Some genera of airborne fungi, such as *Alternaria* sp., *Aspergillus* sp., and *Cladosporium* sp., occur worldwide[20]. The distribution of fungi differs according to season and the type of environment (indoor or outdoor)[21]. This compilation of studies of airborne fungi shows that the same high-incidence genera of fungi were found outdoors in different cities at different times of the year [14,26].

A pioneering study of the prevalence of airborne fungi in Porto Alegre published in 2001 showed that the most prevalent genera were *Cladosporium* sp., *Aspergillus* sp., *Penicillium* sp., *Curvularia* sp., *Alternaria* sp., *Fusarium* sp., and others[21]. Similar results were found in 2021 in Pelotas, where the following genera were identified: *Cladosporium* sp. (18.22%), *Alternaria* sp. (13.84%), *Penicillium* sp. (10.20%), *Curvularia* sp. (7.47%), and *Aspergillus* sp. (3.28%)[24]. In a similar study in Fortaleza in 2004, the most prevalent genera were *Aspergillus* sp., *Penicillium* sp., *Curvularia* sp., *Cladosporium* sp., *Mycelia sterilia, Fusarium, Rhizopus, Neurospora* sp., *Rhodotorula* sp., and *Aureobasidium* sp., while in Recife and Natal, cities with identical climates, *Aspergillus* sp. and *Penicillium* sp. were the most frequent[20]. In São Luís, the most prevalent genera in outdoor environments were *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., *Curvularia* sp., and *Fusarium* sp.[14] The results of these studies are consistent with the findings of a similar study undertaken in the Metropolitan Area of Sao Paulo, which reported that *Penicillium* sp. and *Aspergillus* sp. were the most prevalent species in both indoor and outdoor environments[27].

The findings reveal the constant presence of spores from the genera *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., *Curvularia* sp., and *Fusarium* sp. across Brazil over the ten-year study period.

This review also included studies that demonstrated the prevalence of airborne fungi in indoor environments. A study in the state of Pernambuco evaluating the microbiological quality of environments in a university identified the following genera: *Aspergillus* sp., *Penicillium* sp., *Talaromyces* sp., *Curvularia* sp., and *Paecilomyces* sp. The frequency of *Aspergillus* sp. and *Penicillium* sp. was 50% and 21%, respectively[12]. In a study investigating the diversity of airborne fungi in a library in the state of Mato Grosso, Júnior et al. found that *Aspergillus* sp. was one of the most prevalent fungi, being identified in 89.6% of the samples. *Penicillium* sp. was identified in 10.4% of the samples[19]. Another study that monitored the microbiota of the air in a library in São José do Rio Preto in 2020 identified *Aspergillus* sp., *Cladosporium* sp., *Penicillium* sp., *Scopulariopsis* sp., and *Trichoderma* sp.[28] Similarly, a study in Rio de Janeiro evaluating the impact of the demolition of a hospital wing on the concentration of fungi found that the most frequent genus was *Cladosporium* sp. (mean of 45.09 CFU/m^3 of air), followed by *Penicillium* sp. (mean of 14.35 CFU/m3) and *Aspergillus* sp. (mean of 9.22 CFU/m3)[29].

Airborne fungi can be used as bioindicators for environmental monitoring[30]. A study conducted in 2020 investigating correlations between airborne fungi and air pollutants found that a reduction in the circulation of vehicles due to a truck driver strike had an influence on fungal growth. During the strike, there was an 80% increase in the number of atmospheric fungi, representing a significant difference ($p < 0.05$) when compared to previous periods before the strike[31].

Airborne fungi and implications for allergic reactions

Fungal spores are aeroallergens that can be inhaled and are associated with various respiratory diseases, including allergic rhinitis and allergic asthma20. Groups of fungi that release airborne spores include zygomycetes, ascomycetes, basidiomycetes, and deuteromycetes. It is in the latter group that the allergens *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., and *Alternaria* sp. are found[26].

Human beings are constantly exposed to bioaerosols and fungal spores during their personal and professional lives, constituting a potential occupational *biological hazard*[14]. High concentrations of spores in the air can lead to hypersensitivity of the respiratory tract and increase symptoms that are typical of the sick building syndrome, such as pneumonia, allergic rhinitis and sinusitis, lack of concentration, and fatigue[23,32].

Skin tests and measures of specific IgE antibody levels for airborne fungi were used in a study in Porto Alegre, which demonstrated that 15.38% of atopic individuals with asthma and/or rhinitis had sensitivity to airborne fungi[26]. A study in São Luís with 100 children reported increased concentrations of IgE in 96.9% of patients with allergic asthma and/or rhinitis. Seventy-five per cent of the children tested positive for *Aspergillus*, 87% for *Penicillium*, 46% for *Neurospora*, and 45% for *Fusarium*[33]. A similar study in São Luís analyzing IgE antibody levels against airborne fungi in atopic adults found that 79.7% tested positive for *Penicillium*, 77.8% for *Neurospora*, and 44.9% for *Aspergillus*[34].

In a study in Fortaleza that performed skin tests on individuals with respiratory allergies using fungal extracts, all patients had positive reactions to extracts of *Aspergillus, Alternaria*, and *Drechslera* and 70% had positive reactions to extracts of *Penicillium* and *Curvularia*. None of the patients from the control group had positive skin test reactions35.

The characterization of airborne fungal microbiota helps guide epidemiological research and the diagnosis and treatment of allergic reactions[12]. The allergies addressed by the studies demonstrate the capacity of airborne fungi to cause reactions in individuals who are predisposed to producing IgE response to environmental allergens.

Airborne fungi and implications for fungal infections

It is known that airborne fungi are important biological air contaminants; however,

according to ANVISA, the presence of pathogenic or toxigenic species in the air is unacceptable when assessing the air quality of indoor environments[18]. Fungal infections caused by airborne microorganisms, especially hospital-acquired infections, have received much attention in the medical literature in recent years. The patients most affected by opportunistic mycoses are immunocompromised patients, such as cancer, transplant, AIDS, and polytraumatized patients and neonates[36,37]. Nosocomial infections are particularly associated with fungi from the following genera: *Aspergillus* sp., *Cladosporium* sp., *Paecilomyces* sp., *Penicillium* sp., and *Scopulariopsis* sp., and, to a lesser extent, *Candida* sp., *Rhodotorula* sp., *Cryptococcus* sp., and *Trichosporon* sp.[22]

A quantitative evaluation of fungi in the air of three ICUs in Porto Alegre showed a marked

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predominance of the genera *Cladosporium* sp. in indoor environments and *Penicillium* sp. in outdoor environments, followed by species from the genus *Aspergillus* sp. (predominantly *A. fumigatus*, *A. niger*, and *A. flavus*)[23]. These results are similar to those of a study conducted in an ICU in Pelotas, which found that the most prevalent genera were *Penicillium, Aspergillus*, and *Cladosporium*[15].

Similar results were found in a study in an ICU in Mato Grosso, which reported that the most frequent genera were *Aspergillus* sp., *Penicillium* sp., and *Cladosporium* sp.[38] A study in the surgical center and adult and neonatal ICUs in a hospital in Araraquara found that the most prevalent genera were *Cladophialophora* sp., *Fusarium* sp., *Penicillium* sp., *Chrysosporium* sp., and *Aspergillus* sp.[39]

In contrast, a study of ICUs and wards in two hospitals in Fortaleza isolated four genera of yeast not found in studies in the south of the country: *Candida sp.*, *Rhodotorula sp.*, *Trichosporon sp.*, and *Saccharomyces* sp.[22] A study in Sergipe isolated four genera of fungi in the surgical center, four in the intensive care center, four in the IUC, and five in the burn unit. The following genera were found: *Aspergillus* sp. (43%), *Penicillum* sp. (12%), *Fusarium* sp. (11%), *Candida* sp. (6%), and *Curvularia* sp. (5%)[40]. Finally, a study evaluating air conditioners in public and private ICUs in the state of Piauí, in the northeast region, found that the predominant genus was *Aspergillus* sp. The most prevalent species was *A. niger*, followed by *A. fumigatus, Trichoderma koningii*, *A. flavus*, and *A. tamarii*[32].

The results of this review demonstrate a high diversity of fungal microbiota in the air of hospital environments in Brazil, with the predominance of the genera *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., *Fusarium* sp., and *Candida* sp. *Aspergillus* sp. makes an evident contribution to the composition of this microbiota and implications include occupational health problems and infection.

The toxicity of species from the genera *Aspergillus* sp., resulting from their capacity to produce aflatoxin that can cause poisoning, is widely documented in the literature[36].

Aspergillosis is a type of mycosis caused by the inhalation of spores from the genus *Aspergillus* sp., which can develop into allergic bronchopulmonary aspergillosis and other invasive and systemic conditions. The etiologic agents most involved in these conditions are *A. fumigatus, A. flavus*, and *A.niger*[19,32]. Invasive aspergillosis is common in patients with neutropenia and chronic obstructive pulmonary disease and has been increasingly identified in non-neutropenic patients admitted to ICUs[23]. *A. flavus* is associated with pulmonary infections in immunocompromised patients, *A. fumigatus* is the main agent involved in aspergillosis, and *A. niger* is frequent in otomycosis[32].

The genus *Cladosporium* sp. is also common in hospital environments. This fungus influences seasonal allergies and is associated with central nervous system infections such as the formation of brain abscesses[41].

Another genus commonly found in hospital environments is *Penicillium* sp. Though widely known for its role in the development of antimicrobials, this genus includes fungal air pollutants that can cause penicilliosis when inhaled by immunosuppressed individuals. This disease initially affects the lungs and develops into a systemic disorder[12,19,23]. *Penicillium* sp. is also associated with disseminated infections, such as multiple brain abscesses, peritonitis, and pneumonia in immunocompromised patients[15].

Airborne fungal infections in hospital environments can involve different transmission mechanisms, including the inhalation of fungal spores transported and distributed by contaminated ventilation or air condition systems and contact with surgical wounds, surgical instruments, or the clothing and hands of medical staff [22,37]. This review focused on airborne fungi and therefore the most documented mode of transmission is certainly inhalation.

The literature underlines that air conditioning systems are key sources of dissemination of fungal spores, highlighting the importance of installing high efficiency particulate air filtration systems in health services as a way to improve indoor air quality[38,39].

This study shows the importance of determining the prevalence of fungi in the environment and understanding the different mechanisms through which airborne fungi cause complications, health problems, and even death. Health professionals need to be aware of the various forms of fungal contamination in order to improve health care delivery. It is important to promote the adoption of preventive measures such as the use of personal protective equipment, raising awareness of fungal infections, and investment in adequate ventilation systems, including regular cleaning of air conditioners and the use of filters.

Conclusion

The study of airborne fungi in Brazil is a diverse field and has gained increasing prominence recently. The large concentration of airborne spores in both internal and external environments and potential contamination with airborne microorganisms highlights the importance of this study. The most prevalent genera of airborne fungi in Brazil are *Aspergillus* sp., *Penicillium* sp., *Cladosporium* sp., *Curvularia* sp. and *Fusarium* sp. High concentrations of spores in the air can lead to hypersensitivity and symptoms that are typical of the sick building syndrome, such as allergic rhinitis and sinusitis, lack of concentration, and fatigue. Allergic reactions mainly affect atopic individuals. Airborne fungi can be both pathogenic and toxigenic, causing invasive fungal diseases with disastrous consequences for immunosuppressed patients.

Study limitations include only including articles written in Portuguese and English and limiting the focus to Brazil. Unfortunately, there are few studies addressing airborne fungal microbiota in Brazil and therefore the sample of articles selected for this review was not very robust.

Given the importance of the study topic, further research should be conducted in this area in Brazil. This review seeks to contribute to discussions on the development of public health policies addressing microbiological air quality.

Collaborations

Data curation, formal analysis, research, methodology, writing – original draft: MB Suehara. Conceptualization, data curation, formal analysis, financing acquisition, research, methodology, project administration, supervision, validation, visualization, writing – review and edition: MCP Silva.

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