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**REVIEW ARTICLE** **OPEN ACCESS**

# Diversity, Distribution and Implications of Airborne Fungi: A Comprehensive Review of Research in Different Environmental Settings

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**ABSTRACT-**

*This review aims to synthesize findings from last 10 years research papers conducted in various environmental settings to provide a comprehensive overview of airborne fungi diversity, distribution and their implications. We systematically and comprehensively reviewed all studies of the diversity, distribution and implications of airborne fungi in different environmental contexts from the PubMed and Scopus. Studies that did not address these key aspects were excluded from the analysis. The 29 selected studies of last 10 years encompassed a wide range of locations and environmental settings, including urban, agricultural, clinical and industrial contexts. The findings revealed the diverse nature of airborne fungi, their seasonal variations and their associations with various environmental factors such as temperature, humidity and land use. Aspergillus and Penicillium found prevalent. Hospitals, schools, university campus, industries, caves, buildings etc. are the major source airborne fungi and contaminate air. As human and other living animals directly come in contact with these places, it adversely affects health. This may be the major reasons of increasing cases of allergies and asthma worldwide.*

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## INTRODUCTION

Fungi constitute a significant component of the airborne microflora and are not limited to the atmosphere; they are also widely distributed in terrestrial environments such as soil, water, and decomposing plant matter [1]. Airborne spore dispersal serves as a pivotal mechanism for the reproductive spread of numerous fungal genera [2,3]. The modest size and hydrophobic nature of fungal spores enable their long-distance dispersion, which can have adverse effect for both human and plant health [4,5]. A substantial proportion of airborne spores emanates from agricultural and outdoor settings [6] and the distances they travel are contingent upon a multitude of factors [7]. The density of airborne microorganisms shows variations based on topological features, geographic locations and seasonal shifts [8,9,10]. Alteration in relative humidity can also impact the quantity of fungus spores [11]. Generally, urban areas tend to exhibit a higher concentration of airborne microorganisms compared to rural areas [12].

The significance of airborne fungal contaminants has garnered increased attention due to the health risks posed by fungal spores themselves or their metabolic byproducts [13]. Certain genera that is commonly associated with allergies, such as *Alternaria spp., Aspergillus spp., Cladosporium spp*., and *Penicillium sp*., being prevalent [14-15].

Apart from the possibility of fungal infections, which can vary from minor to fatal nosocomial kinds, fungi also have allergic and toxic properties, along with their inflammatory effects, have been identified as potential health impacts of fungal bioaerosols [16]. Numerous studies have suggested that indoor airborne culturable fungi may contribute to the sick building syndrome [17] and respiratory and/or allergic diseases, exacerbating asthma and in severe cases, leading to asthma-related deaths and infections [18,19]. Moreover, volatile organic compounds emitted by outdoor fungi have been implicated in affecting human health, causing symptoms such as lethargy, headache and irritation of the eyes, as well as irritability of the nose and throat mucous membranes [20].

Allergic rhinitis affects approximately one in five individuals worldwide, with its prevalence increasing with age [21]. The symptoms of this illness appear following exposure to airborne allergens. Additionally, up to 40% of people with allergic rhinitis also have asthma, which can make respiratory symptoms severe after exposure [22]. Under extreme conditions, such exposure can provoke acute asthma exacerbations leading to hospitalization, particularly during thunderstorm asthma events [23]. As to Backman et al. **,** there has been a rise in the incidences of asthma from 8.4% (95% CI: 7.8-9.0) in 1996 to 9.9% (95% CI: 9.2-10.6) in 2006 and 10.9% (95% CI: 10.1-11.7) in 2016 (P<.001) [24]. Notably, in Italy an increase in the prevalence of asthma from 4.1% to 6.6% between 1990 and 2010, with wheezing and allergic rhinitis also experiencing a rise from 10.1% to 13.9% and 16.8% to 25.8%, respectively [25]. Remarkably, there has been considerable variation in worldwide estimates of the prevalence of asthma [26].

Despite the acknowledged hazards related to airborne fungi, the study of airborne microorganisms has been relatively underemphasized, particularly in recent years. This research looks into the makeup and range of airborne fungus in various geographic areas, reviewing 30 research articles published within the last decade. By focusing on the most recent findings, we seek to bridge this knowledge gap and provide a comprehensive overview of airborne fungal research, with implications for environmental and health management.

## MATERIAL AND METHODS

### Procedure and registration:

The present study was done by using the guidelines issued for preferred reporting material for systematic review (PRISMA-P) and the findings were noted in a systematic manner. Cochrane and PRISMA guidelines were considered as the guiding articles for this review.

### Literature search:

For conducting this study, the required literature was accessed from online databases PubMed and Google Scholar. The relevant keywords and phrases used for the search are: Airborne fungi, Fungal diversity, Environmental settings, Air quality, Health implications. One of the linguistic barriers for the search was the need of the article to be in English. The detailed information of overall studies used in this systematic review is mentioned in fig. 1. However, it is important to notify that search syntaxes were customized according to database requirement.

### Eligibility Criteria:

To execute the study, a certain set of eligibility criterions was taken in consideration which can be further divided into inclusion and exclusion criteria.

**Inclusion Criteria**:

- Published article between 2013 to 2023.
- The review selected only those literature in which the diversity, distribution and implications of airborne fungi were documented with different environmental settings.
- Only full text literatures were taken into consideration.
- The published literature must be in English language only.

**Exclusion criteria:**

- Volume chapters
- Short communication
- Duplicate literature
- Articles which were dated to more than 10 years back.
- Patents
- Systematic review
- Conference articles.

### Data Analysis:

After selecting literature from various databases, they were organized systematically in an excel sheet. All sorts of duplicate or triplicate articles were removed. A total of 608 study were screen for the present systematic review. After excluding the repeated articles, 29 published articles of last 10 years were included in the study.

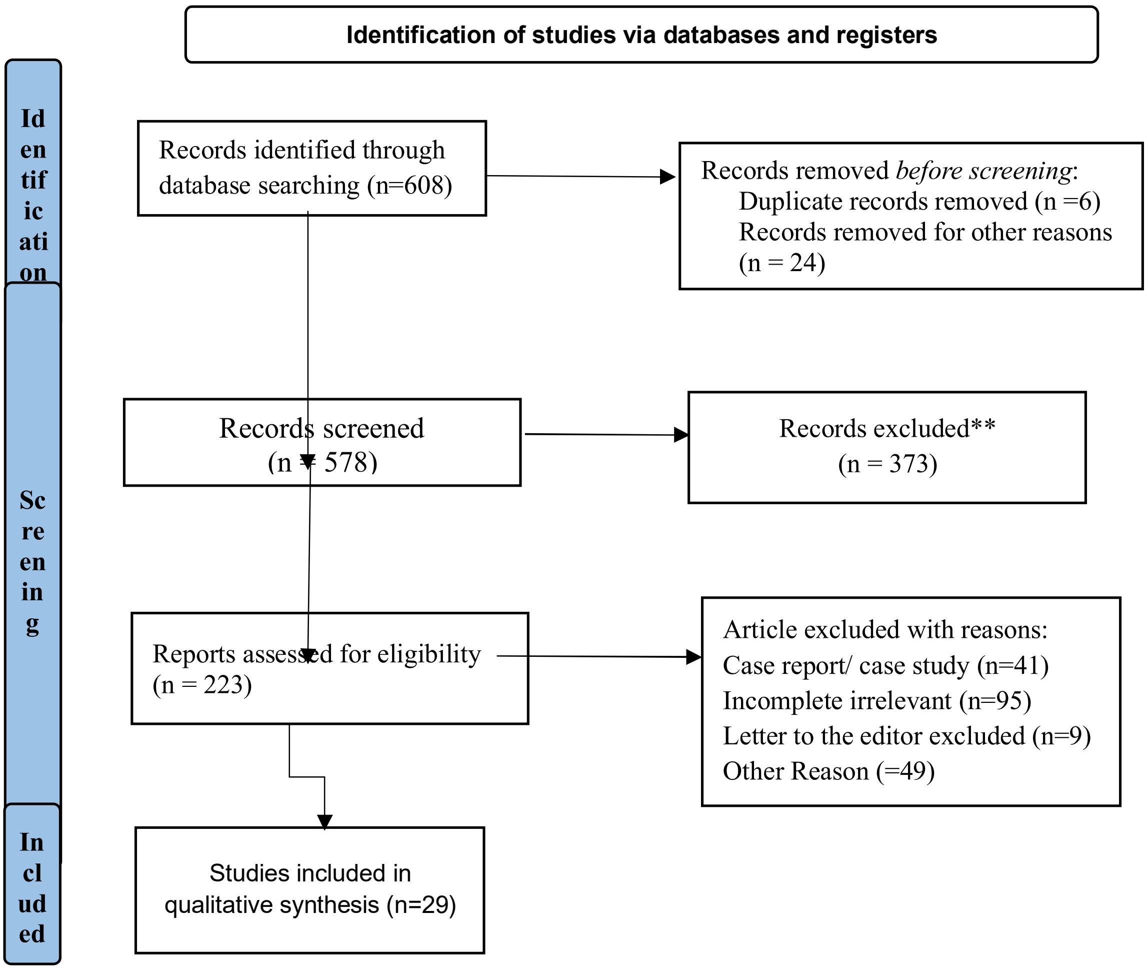


**Figure 1:** Flow diagram for new systematic review which included search of databases and resisters only.

**RESULTS**

In this systematic review, 608 articles were initially searched and analyzed. Upon further evaluation, 06 articles were removed from the studies to be reviewed due to their duplicity and 24 due to full text unavailability and irrelevance to the concept to be studied.

Apart from this, from the remaining articles that were retrieved from all the databases, 373 articles were excluded as this were inaccessible and was in a foreign language. 194 were excluded as those were case report/ case study (n=41), incomplete irrelevant (n=95), letter to the editor (n=9) and other reason (=49). After performing complete screening and analysis of data, a total of n=29 articles were selected on the basis of the specified inclusion criterions (table no.1). Articles published between 2013 to 2023 passed the set criterions. In the present review studies focusing on diversity, distribution and implications of airborne fungi. The study include in this comprehensive review were from different environmental settings.

**Table 1: Fungi Identified Techniques done by Various Researcher**

| Year | Reference | Country | Primary Focus | Fungi Species Identified | Technique for Airborne Fungi |
|---|---|---|---|---|---|
| 2013 | Almaguer et al. | Cuba | Non-viable | *Cladosporium, Aspergillus, Penicillium* | volumetric Hirst type sampler (Lanzoni VPPS 2000, Bologna, Italy) |
| 2013 | Ponce et al. | Mexico | Seasonal Variation | *Cladosporium spp., Penicillium spp., Aspergillus spp., Fusarium spp., and Acremonium spp.* | Andersen impactor model 10-709 1 ACFM |
| 2013 | Park et al. | Korea | hospital lobbies | NA | Andersen single-stage sampler |
| 2014 | Oh et al. | South Korea | Seoul | *Cladosporium spp,* | |
| 2014 | Shams et. al. | Iran(Tehran | Distribution in Tehran | *Aspergillus (31.3%), Cladosporium (22.1%), Penicillium (13.8%)* and *Alternaria (12.2%).* | settle plate method |
| 2014 | Ogórek et al. | Poland | External Environment | *Aspergillus, Penicillium, Cladosporium* | settle plate method |
| 2014 | Jakšić et al. | Croatia | grain mill and four dwellings (two apartments and two basements) as well as in outdoor | *Cladosporium spp. (90-100 %), Penicillium spp. (40-100 %), and Alternaria spp. (10-100 %), which are common for temperate climates. Aspergilli from the Flavi (50- 100 %) and Nigri (15-40 %) sections as well as A. ochraceus (15-60 %) and Eurotium spp. (85-100 %)* | air-sampler and DG-18 agar plates |
| 2014 | Fernández et al. | Spain | Outdoor | *Alternaria (2.6), Aspergilluse, Penicillium (2.0) and Cladosporium (11.1)* | AES, Burkard spore, AES Chemunex spore trap |
| 2014 | Barontini et al. | Italy | Biofuel Storage | *Aspergillus (30%), Cladosporium (12%)* | BRAVO m2 |
| 2014 | Lee & Liao | China | Agricultural workers' exposure to airborne fungi | *Aspergillus, Penicillium, Cladosporium,* and *Ascospores(15.7 to 99.1% of the total concentration)* | Two stage bio-aerosol cyclone sampler (model BC221) |
| 2014 | Pavan & Manjunath | India | Indoor and outdoor airborne fungi in cowshed | **Indoor** - *Cladosporium (8.13%), Aspergillus (6.41%), and Aspergillus niger (6.1%)* **Outdoor**- *Alternaria alternata (10.85%) and Aspergillus (10.71%)* | Andersen two-stage sampler |
| 2015 | Hospodsky et al. | USA | Children's Classrooms | *Cladosporium, Alternaria, and Epicoccum spp* | Impactor (NewStar Environment, Roswell, GA, USA)and agar plates |
| 2015 | Crawford et al. | New York | Urban Homes | *Aspergillus, Penicillium, Cladosporium* | Impactor and agar plates |
| 2015 | Almaguer et al. | Cuba | - | *Cladosporium cladosporioides, Cladosporium cladosporioides, Leptosphaeria, Coprinus, Aspergillus, Penicillium* | volumetric Hirst type sampler (Lanzoni VPPS 2000, Bologna, Italy) |
| 2015 | Li et al. | China | university environments | NA | Andersen six-stage cascade impactor (Westech) with six glass petri dishes of 93 mm in diameter |
| 2016 | Kumari et al. | Koria | Swine Houses | *Ascomycota (75.4% ), Basidiomycota (15.3%), Zygomycota (4.2%), and Glomeromycota (1.5%)* | Autoclaved cellulose nitrate filters (0.22 µm; Fisher Scientific, Pittsburgh, PA) |

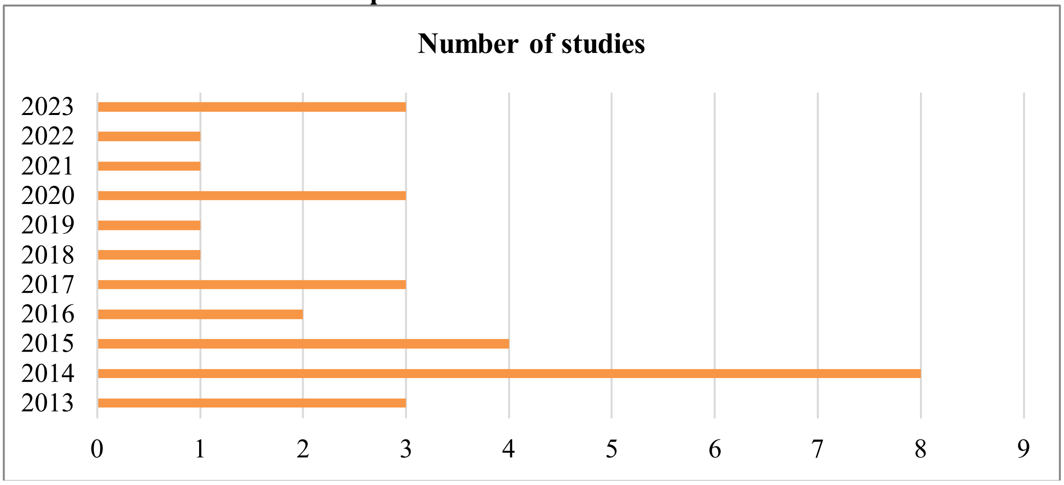
| | | | | | |
|---|---|---|---|---|---|
| 2016 | Wang et al. | China | Shanghai Residences | NA | Microflow (AQUARIA Inc., Italy) |
| 2017 | Tong et al. | China | Hospital Environment | *Aspergillus (61%)* | high-volume samplers |
| 2017 | Kowalski et al. | Poland | Wastewater Plants | *Cladosporium, Penicillium* | six-stage Andersen impactor. |
| 2017 | Gonçalves et al. | Brazil | Intensive Care Unit | *Penicillium spp. (15.18%), Aspergillus spp. (13.92%), Cladosporium spp. (13.92%)* | Andersen N6 sampler |
| 2018 | Patel TY et al. | USA | Desert Urban | *Smuts, Cladosporium* | Burkard spore trap |
| 2019 | Abbasi et al. | Iran | Indoor/Outdoor of Hospital | *Fusarium spp., Penicillium spp., Paecilomyces spp., and Aspergillus niger* | Settel Plate Method |
| 2020 | Qi et al. | China | Temporal-spatial | **Mountain-***Malassezia (2.70%), Aspergillus (3.02%) and Penicillium (2.78%).* **Urban region-** *Aspergillus (3.86%), Cryptococcus (3.20%) and Trichosporon (1.81%)* | Air particulate matter sampler (ZR-3930, Qingdao, China) |
| 2020 | Odebode et al. | Nigeria | Various Locations | *Aspergillus niger (14.47%), Aspergillus sydowii (10.37%), and Aspergillus flavus (7.93%). Penicillium funiculosum (5.49%), Neurospora crassa (5.32%), Penicillium oxalicum (4.71%), Penicillium pinophilum (2.88%), Fusarium verticillioides (3.05%), Penicillium simplicissimum (1.83%), Rhizopus oryzae (4.10%) and Mucor sp. (3.44%).* | Andersen N6 sampler |
| 2020 | Mirhoseini et al. | Iran | Pediatric Hospital | *Cladosporium spp. (19%) Penicillium spp. (16%), Aspergillus spp. (16%) and Paecilomyces spp. (10%)* | single-stage Andersen sampler |
| 2021 | Dominguez et al. | Spain | Show Caves | *Cladosporium cladosporioides, Parengyodontium album and Penicillium chrysogenum* | Duo SAS Super 360 (International pBI, Milan, Italy) |
| 2022 | Verma D. | India | Thar Desert-Bikaner, | *Cladosporium (24.95%), Alternaria (23.02%) and Curvularia (11.53%)* | Gravity Slide Method |
| 2023 | Yang et al. | China | Wuhan City | *Cladosporium (36.36%), Ustilago (20.12% and Alternaria (13.87%)* | volumetric Hirst spore trap (Burkard Manufacturing, Rickmansworth, UK) |
| 2023 | SenGupta et al. | India | Kolkata City | *Ascospores, Cladosporium spp., Asper gillus, Penicillium spp., and basidiospores* | Microscopy-based and culture-based methods |
| 2023 | Harsh et al. | India | Public building in a small rural town. | *Cladosporium* | Open plate method |

## Diversity and distribution of airborne fungi:

The investigation covered 24 countries across various regions and climates. North America represents 4.17% of the dataset, with the USA (New York) featuring a humid subtropical climate. Central America's Mexico displayed a range from tropical to arid climates (4.17%), while Cuba in the Caribbean had a tropical climate with wet and dry seasons (4.17%). South America's Brazil featured tropical conditions in the north and subtropical in the south (4.17%). Europe included Poland with a temperate climate and distinct seasons, Croatia with Mediterranean and continental climates and Spain and Italy with diverse climates, including the Mediterranean (16.67%). In Asia, South Korea had a temperate climate, Iran (Tehran) exhibited a continental climate, China had a vast array of climates and India featured varied climates influenced by the Indian monsoon (33.33%). Nigeria in West Africa had a tropical climate with wet and dry seasons (4.17%).

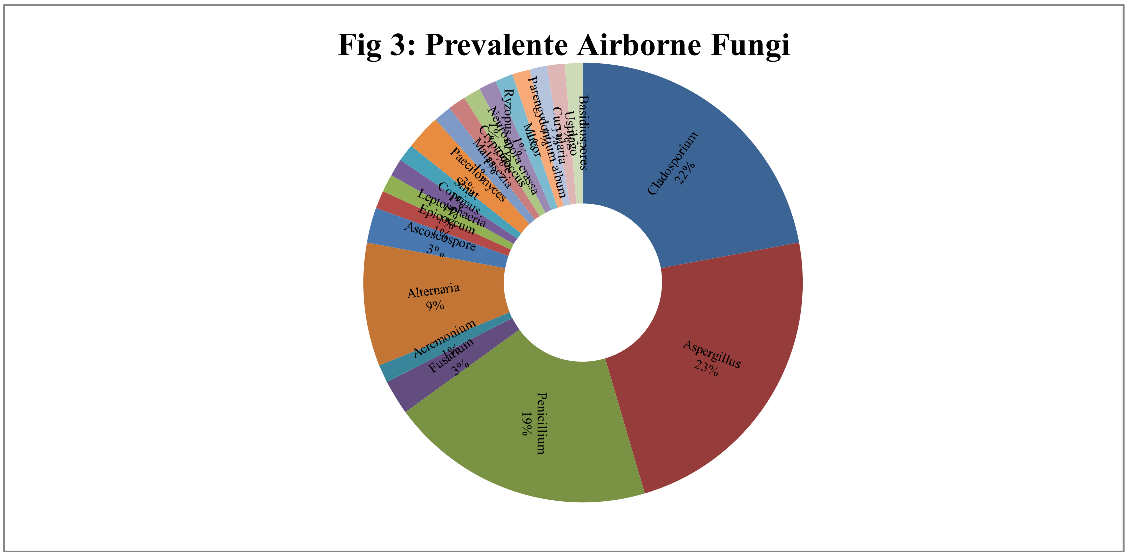
Majority of the studies were conducted in year 2014 (n=8) and 2015 (n=4) at different indoor and outdoor environment.

**Figure 2: This figure illustrates the distribution of studies on airborne fungi conducted overthe period from 2013 to 2023.**




By analysing 30 research paper, a total of 21 different species of airborne fungi were observed (from different places such as hospitals, indoor of building, school, classroom, university campus, cowshed, industry, waste water sites, caves etc.).

The most predominantly observed fungal species in the dataset include *Aspergillus* (85.71%), *Cladosporium* (80.95%), *Penicillium* (71.41%) and *Alternaria* (33.33%). In contrast, the least observed species are *Acremonium, Smuts, Epicoccum, Leptosphaeria, Coprinus, Malassezia, Cryptococcus, Neurospora crassa, Ryzopus oryzae, Parengydontium album, Curvularia, Ustilago, Basidiospores* and *Mucor sp*., each with minimal occurrences, representing 4.76% of the total observations. Out of thirty studies, three papers did not specify the species that were seen, which could have determined only the percentage of fungi that were found there.




**Outcomes of the study-**

In this comprehensive study of airborne fungal populations, the analysis revealed consistent trends across multiple research articles. Geographic and seasonal factors were found to exert a statistically significant influence on the composition of airborne fungi, with a unanimous agreement among all the studies (n=5, 100%)[27-31].These factors showed that airborne fungal populations are not static but dynamically respond to changes in environmental conditions and geographic locations. Additionally, the research unequivocally confirmed the presence of allergenic and potentially pathogenic fungal species in the air, emphasizing a crucial aspect of airborne fungal ecology. All the studies (n=3, 100%)[32-34]identified such species in the sampled environments.

Furthermore, the investigation demonstrated that environmental variables, including temperature, humidity and pollution levels, exerted a statistically notable impact on the abundance and diversity of airborne fungi. Again, the data from all the studies (n=3, 100%)[27,30-31]underscored the significance of these factors in shaping fungal populations in the air. Moreover, distinctions between indoor and outdoor air with respect to fungal composition were consistently observed (n=2, 100%)[31, 35],highlighting the importance of managing indoor air quality, especially in enclosed spaces like healthcare facilities and residences.

The study outcomes also provided robust evidence for potential health implications associated with airborne fungi exposure, particularly concerning respiratory diseases. All studies (n=2, 100%)[32, 36] reported a statistically significant correlation between fungal exposure and respiratory health risks. This information is crucial for healthcare practitioners and public health officials. Finally, the results emphasized the need for continuous monitoring of airborne fungi as all studies (n=2, 100%) underlined the importance of ongoing surveillance to assess air quality and health risks [27,28].

**DISCUSSION-**

The comprehensive review of research on airborne fungi conducted across various environmental settings has yielded valuable insights into the diversity, distribution, and implications of these microorganisms. The findings from this study are significant, particularly in the context of public health and environmental science.

The data encompassing 24 countries from different regions and climates shed light on the global presence of airborne fungi. The representation of various climate types, from humid subtropical in the USA to arid in Mexico, tropical in Cuba, and temperate in Poland, offers a diverse snapshot of the world. The pre-eminence of certain fungal species, including *Aspergillus, Cladosporium, Penicillium* and *Alternaria*, across different environmental settings underlines their adaptability and prevalence. It's noteworthy that some less common species, such as *Acremonium, Smuts* and *Mucor sp*., were found with minimal occurrences, comprising only 4.76% of the total observations.

These findings are consistent with previous studies conducted worldwide. As a similar study by Yanga et al. (2023) in Wuhan, China, revealed, the diversity and distribution of airborne fungi vary with geography and environmental conditions [37]. The predominance of *Aspergillus* and *Cladosporium* is in line with the research by Qi et al. (2020)[27] and Verma (2022)[28]. Such patterns lend credence to the hypothesis that seasonal and geographic variables significantly influence the distribution of airborne fungus populations [27-31].

One of the most critical findings of this comprehensive review is the unequivocal presence of allergenic and potentially pathogenic fungal species in the air across different environmental settings. Various studies, identified these species in sampled environments [32-34]. This highlights the importance of understanding the health implications associated with airborne fungi exposure, especially concerning respiratory diseases. Studies done by Fernández et al.[36] and Gonçalves et al.[32] reported a statistically significant correlation between fungal exposure and respiratory health risks. These results underscore the need for healthcare practitioners and public health officials to address this issue proactively.

The findings highlight the significant influence of environmental variables, specifically temperature, humidity and pollution levels, on the diversity and abundance of airborne fungi, corroborated by studies done by Kumari et al.[30], Mirhoseini et al.[31] and Qi et al [27]. Warmer seasons, characterized by elevated temperatures and humidity, have been shown to significantly impact fungal composition, leading to increased diversity due to more favorable growth conditions [27,30-31]. Conversely, cooler seasons are associated with reduced fungal diversity. Additionally, the distinction between indoor and outdoor air composition, observed in several studies [33,35], underscores the critical need for managing indoor air quality. Indoor environments host specific fungal species, including *Aspergillus* and *Penicillium*, influenced by building materials and human activities, which may pose health risks[31,35]. In contrast, outdoor air harbors a different fungal profile, influenced by natural sources and characterized by species like *Cladosporium* and *Alternaria,* with implications for allergies and respiratory sensitivities. These insights emphasize the importance of understanding environmental factors in shaping airborne fungal populations and their relevance for health and indoor air quality management. The findings offer valuable information for healthcare practitioners and public health officials to comprehend the seasonality of airborne fungi and the distinct microbial profiles indoors and outdoors, allowing for better strategies to mitigate health risks and enhance indoor air quality.

The results of this study also underscore the necessity for continuous monitoring of airborne fungi. All studies, including those by Qi et al. [27] and Verma [28], emphasized the importance of on-going surveillance to assess air quality and associated health risks. These findings coincide with the recommendations of Hughes et al., who pointed out the significant impact of fungal spores on asthma prevalence and hospitalization [38].

**CONCLUSION-**

Environmental factors significantly affect airborne fungi, with seasonal variations playing a crucial role. Indoor air quality management is essential, especially in healthcare facilities. Fungi such as *Aspergillus and Cladosporium* which raise respiratory health concerns noted dominant.

**LIMITATIONS-**

This study has certain limitations. Firstly, the diverse geographic locations and climates of the included studies make it challenging to generalize findings. Temporal variations and the reliance on data spanning from 2013 to 2023 could introduce bias. The majority of studies are observational and cross-sectional, limiting the ability to establish causal relationships. Methodological differences among the studies also affect data comparability. Lastly, the study primarily focuses on the presence and diversity of airborne fungi without delving into specific health implications or molecular aspects.

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