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IMPACT OF AIRBORNE FUNGAL SPORES ON HUMAN AND CROP HEALTH IN INDIA

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ABSTRACT

Allergic conditions, including bronchial asthma, allergic rhinitis, and atopic dermatitis, affect more than 20-30% of the world's population. These disorders are frequently caused by bioparticulates, such as fungus spores, dust mites, insect debris, and pieces from plants and foods. In order to effectively manage these allergies, it is crucial to have a comprehensive awareness of the daily, seasonal, and yearly fluctuations in the levels of these biological particles in the atmosphere. This paper examines aerobiological studies carried out in several parts of India, with a specific focus on the occurrence and seasonal patterns of fungal spores, which play a crucial role in causing allergic reactions. Thorough experiments have been conducted to ascertain the concentration of fungal spores in various habitats and monitor their seasonal variations. The key findings suggest that fungal spores are present in both indoor and outdoor contexts. Notable examples include Aspergilli-Penicilli, Cladosporium, Ascospores, Alternaria, Dreschlera, Epicoccum, Nigrospora, and Basidiospores. Some clinically significant fungal allergens that have been identified include species such as Aspergillus fumigatus, Aspergillus flavus, Aspergillus nidulans, Alternaria alternata, Cladosporium cladosporoides, Ganoderma lucidum, Mucor mucedo, Fusarium solanii, Curvularia lunata, Neurospora sitophila, and Scopulariopsis brevicaulis. The review emphasizes the importance of monitoring the atmospheric concentrations of these allergens in order to enhance diagnostic and treatment strategies for allergic disorders. Gaining insight into the dispersion and diversity of allergies is essential for formulating specific approaches to managing them and improving the well-being of persons impacted by allergic reactions.

Keywords: Fungal Infection, Fungal Spores, Crop Health, Airborne Fungus

1. INTRODUCTION

The atmosphere contains a significant quantity of bioparticles and compounds, many of which are potentially detrimental to the human respiratory system. These bioparticles consist of pollen grains, fungal spores, insect waste, plant fragments, animal dander, mites, and similar organic materials. These naturally derived components are well-established agents in triggering respiratory disorders such as asthma, allergic rhinitis, and atopic dermatitis [1], [2].

India's economy has undergone rapid growth due to intense industrialization and urbanization over the past few decades. However, this economic advancement has simultaneously led to a severe decline in ambient air quality. The deteriorating air quality is attributed to an increase in airborne pollutants and bioparticulates, including fungal spores, which have been identified as major contributors to allergic respiratory diseases. These effects are more pronounced in densely populated urban areas, where pollutant concentrations are considerably higher than in rural regions [2], [3].

Epidemiological studies across various global and Indian regions clearly reveal that the prevalence of respiratory allergies is on the rise. Recent assessments estimate that 20–30% of the global population suffers from airway allergies, and a significant portion of these cases are exacerbated or even directly caused by airborne fungal spores [4], [5]. Fungal spores are known to have potent allergenic properties, and individuals who are sensitized to them frequently experience episodes of bronchial asthma, conjunctivitis, rhinitis, and dermatitis. Accurate and detailed knowledge of the atmospheric dynamics—including daily, seasonal, and annual variations—of fungal spores is essential for diagnosing and managing allergic disorders more effectively [6]. In this context, the preparation of national and regional aerobiological calendars proves extremely useful for clinicians and allergists. These calendars assist in tracking the temporal distribution of allergenic particles and guide physicians in offering timely and specific therapeutic recommendations to patients [7].

India, with its vast geographic expanse and rich biodiversity, harbors a population exceeding 1.2 billion and encompasses a multitude of climatic zones, ecosystems, religions, and cultures. This environmental diversity makes it one of the most biologically varied regions on the planet and a particularly significant area for aerobiological studies [6], [8]. The country also boasts one of the richest floristic compositions in the world, contributing to a diverse airborne bioload, including pollen and fungal spores. Historical records indicate that India was among the earliest nations to initiate aerobiological investigations, with preliminary studies tracing back to the 19th century [6].

The importance of fungal spores as airborne allergens was first documented as early as 1726, when Blackley suggested that species such as Chaetomium and Penicillium were implicated in respiratory illnesses referred to as "bronchial catarrh" at the time [6], [9]. Later, in 1924, van Leumen identified fungi like Aspergillus, Mucor, and Penicillium as causative agents for allergic reactions [6]. Following these early discoveries, scientific interest in aerobiology gained momentum. Numerous researchers across the globe, including in India, began conducting airborne fungal surveys using a range of techniques—such as volumetric samplers, rotorod samplers, and gravitational settling plates—to identify prevalent airborne fungal taxa and evaluate their clinical significance in sensitized populations [6], [10].

The current review synthesizes data from decades of aerobiological research in India, focusing particularly on fungal spores. It highlights their ecological occurrence, seasonal variability, and allergenic potential in different regions of the country. The goal is to establish a scientific framework that can aid in monitoring airborne fungal allergens and formulating strategies for effective diagnosis, management, and public health intervention.

2. MATERIAL AND METHODS:

This review aims to provide a comprehensive analysis of notable aerobiological studies conducted across different regions of India, with an exclusive focus on fungal spores and their implications for allergic disorders. It includes a systematic review of both qualitative and quantitative research related to the occurrence, seasonal variability, and concentrations of airborne fungal spores, evaluated across indoor and outdoor environments. Emphasis has been placed on understanding the spatiotemporal patterns of fungal spore dispersal and their clinical relevance in hypersensitive populations [11].

To ensure the scientific rigor and inclusivity of this review, publications were sourced from both national and international peer-reviewed journals, including specialized aerobiology and environmental health publications. This approach guarantees that the analysis presents a balanced and regionally diverse perspective. Research works ranging from classical studies conducted in Indian metropolises to recent investigations from rural and ecologically sensitive regions have been considered. Special focus was given to papers that offered detailed descriptions of spore morphology, concentrations in the ambient environment, methodological sampling techniques, seasonal trends, and clinical correlations with allergic conditions [11], [12].

One of the primary reference sources for this review is the seminal volume Airborne Pollen, Spores, and Other Plant Materials of India: A Survey by Nair, Joshi, and Gangal [6], which is widely recognized as an authoritative compilation of India's aerobiological data. This comprehensive publication integrates findings from multiple research institutions and government-funded projects across India. It offers a detailed synthesis of atmospheric data related to airborne pollen and fungal spores collected over several decades. The book documents significant findings on indoor and outdoor spore levels, as well as annual and seasonal variations across distinct eco-climatic zones such as the Gangetic plains, Deccan plateau, Himalayan foothills, coastal belts, and arid zones [6], [13].

Furthermore, the studies incorporated in this review span data collection from diverse ecosystems, including high-humidity coastal regions, semi-arid zones, polluted metropolitan cities, and agricultural landscapes. By doing so, the review effectively captures the geographical and ecological heterogeneity of fungal spore prevalence and its potential impact on respiratory health outcomes [12].

Methodologically, the selected studies employed various aerobiological sampling techniques, including gravitational settling methods (settle plates and slides), impaction samplers (Rotorod and aeroscope), and volumetric devices such as Burkard and Anderson samplers. These methods were utilized for consistent monitoring of airborne fungal spores over specified intervals, often ranging from daily to seasonal and annual surveillance [13], [14]. Comparative studies were also included where data were collected from both indoor and outdoor locations such as homes, hospitals, schools, granaries, libraries, poultry farms, and bakeries facilities known to harbor high allergenic bioaerosol loads [15].

The review also includes previously unpublished institutional datasets and observations derived from theses and long-term monitoring programs undertaken by centers such as the National Botanical Research Institute (NBRI), Bose Institute (Kolkata), and regional universities in Maharashtra, Karnataka, Andhra Pradesh, and Uttar Pradesh [6], [13], [16].

Overall, the review integrates these diverse datasets to trace regional and seasonal patterns of fungal spore diversity, linking them to known allergenic outcomes. It underscores the need for continued aerobiological monitoring, standardization of sampling techniques, and multidisciplinary collaboration among botanists, allergists, mycologists, and public health experts. This approach provides a foundation for developing region-specific fungal allergen forecasts and public health guidelines aimed at reducing exposure in vulnerable populations [17].

3. RESULTS AND DISCUSSION

3.1. THE RESULTS HAVE BEEN DISCUSSED IN THE FOLLOWING SUBHEADINGS:

1) Aeropalynological surveys:

The origins of aerobiological research in India can be traced back to the pioneering work of Cunningham in Calcutta (now Kolkata), who was among the first to explore the relationship between airborne particles and zymotic (infectious) diseases [6], [11]. Despite this early initiative, aerobiological research in India faced a substantial hiatus of nearly a century. The field experienced a revival in the mid-20th century with the establishment of key research centers in cities such as Jaipur and Delhi. These centers marked the beginning of systematic aerobiological investigations across different geographical zones of India [6], [13].

One of the most significant revivals of aerobiological research occurred at the Bose Institute in Kolkata under the leadership of Chanda and his associates. Their work was instrumental in producing comprehensive pollination calendars for urban and peri-urban areas such as Kolkata, Falta, and Kalyani. These calendars were critical in documenting the seasonal trends of airborne pollen, which, in turn, provided valuable insights for clinicians dealing with allergic conditions [11], [14].

Simultaneously, Bangalore emerged as another prominent hub for aerobiological research, mainly due to the efforts of Agashe and his team. Their studies were among the first to systematically evaluate the types of airborne bioparticles, including pollen and fungal spores, in the southern parts of India. These researchers emphasized the public health implications of airborne allergens and established long-term observation stations for aerobiological monitoring [12], [15].

Over the years, several more aerobiological research centers were developed across India. These include institutions in Gwalior, Jabalpur, Santiniketan, Manipur, Gulbarga, Thiruvananthapuram, Visakhapatnam, Lucknow, Mumbai, and Bhopal. Each of these centers has made noteworthy contributions to the study of aeroallergens, particularly by linking the presence of airborne fungal spores and pollen grains to respiratory illnesses in atopic individuals [6], [13], [16].

The research undertaken at these centers has greatly enhanced the understanding of the seasonal periodicity, regional variability, and allergenic potential of airborne particles. These studies have laid a strong foundation for the forecasting of allergy outbreaks, supporting healthcare professionals in implementing preventive strategies and timely interventions for allergic patients [17].

The cumulative impact of these aeropalynological surveys across different parts of India has not only led to the establishment of standardized sampling techniques and pollination calendars but has also stimulated interdisciplinary collaboration among botanists, allergists, meteorologists, and public health experts. The data gathered continue to serve as a benchmark for regional aeroallergen monitoring programs and for developing models to predict the burden of allergic diseases in various climatic zones of the country [6], [17].

2) Airborne fungal survey:

Aeromycology in India formally began in 1959 with the foundational work of Sreeramulu in Visakhapatnam, marking a pivotal point in aerobiological research [6], [13]. This was followed by the establishment of centers in Mysore by Ramalingam in 1965 and in Aurangabad by Tilak in 1966 [15]. In 1976, Vittal initiated fungal aerobiology studies in Madras (now Chennai), expanding the scope of fungal spore monitoring [6].

Concurrently, significant clinical work on fungal allergies began in Delhi under Shivpuri and was later extended by Agarwal and Singh, focusing on allergic responses linked to specific airborne fungi [4], [16]. These studies emphasized the health risks associated with inhalation of fungal spores, particularly in sensitized individuals.

Fungal spores are highly persistent in both indoor and outdoor air due to their microscopic size and aerodynamic properties. Studies confirmed their prevalence in various environments such as homes, hospitals, libraries, and industrial settings [6], [14].

Indian aerobiological research has progressed in three main domains: general atmospheric surveys, indoor air quality studies, and agricultural field monitoring. These studies provide foundational data for assessing allergen exposure and developing control strategies for public health and occupational safety [11], [17].

3) Outdoor aeromycoflora:

Aerobiological investigations across India have extensively monitored outdoor fungal spores using gravity-based methods (settle plates, gravity slides), impaction techniques (Rotorod sampler, aeroscope), and volumetric devices (Burkard traps, Anderson samplers) [6], [13]. These methods revealed that Cladosporium is the most dominant genus, followed by basidiospores and ascospores in most geographic locations [12], [15].

In northern India, studies in Dehradun identified major fungal types including Cladosporium, Alternaria, smut spores, Curvularia, Ascospores, Nigrospora, Aspergilli-Penicilli, and Epicoccum, with peak concentrations from July to October [14]. Gupta et al. in Delhi documented 98 fungal species, where Cladosporium contributed 25–40% of total airborne fungi, followed by Ustilago, A. flavus, Alternaria, and A. niger [13].

Surveys in Solan (Himachal Pradesh) and Lucknow identified 17 and 40 fungal species respectively, dominated by Aspergilli-Penicilli, Cladosporium, and Drechslera [14]. In eastern India, studies from Jamshedpur, Imphal, and the Eastern Himalayas found Alternaria, Cercospora, Curvularia, Epicoccum, and Fusarium to be prevalent [6], [18].

Western India studies led by Tilak in Aurangabad showed that Deuteromycetes made up 70% of total spores. Dominant genera included Alternaria, Nigrospora, Curvularia, Stachybotrys, and Memnoniella [15]. Seasonal surveys in Aurangabad and Pune recorded 18 and 22 fungal species respectively, mainly Cladosporium, Rhizopus, and Aspergilli-Penicilli [6].

Southern India reports, especially from Bangalore and Madras, identified Nigrospora, Basidiospores, and Curvularia as predominant, with peak spore load during the South-West and North-East Monsoons [19]. Adhikari et al. found viable fungal concentrations between 72–1796 CFU/m^3 in rural agricultural areas [17].

4) Indoor occupational aeromycoflora:

Humans are constantly exposed to various environmental allergens, not only outdoors but also in indoor occupational settings. In individuals with hypersensitivities, exposure to airborne fungal spores during work hours can trigger or exacerbate allergic symptoms, sometimes persisting even after leaving the exposure site [16], [20].

Although indoor aerobiological research in India is relatively limited compared to outdoor studies, significant surveys have been conducted across workplaces such as hospitals, libraries, poultry farms, bakeries, leather shops, grain storage facilities, and residential buildings [6], [15]. These environments commonly harbor allergenic fungi due to accumulation of organic dust and high humidity levels.

Frequent fungal genera isolated from these indoor environments include Aspergillus, Penicillium, Cladosporium, and other moniliaceous fungi. These fungi are known for their allergenic potential and are frequently implicated in respiratory issues among sensitized individuals [16], [20].

The findings emphasize the critical need for continuous indoor air quality monitoring, especially in workplaces. A better understanding of indoor mycoflora is essential for developing targeted allergen control strategies and ensuring safer occupational environments across India [17], [20].

5) Fungi of allergenic significance:

Fungal species are well known for causing a wide range of allergic responses, especially respiratory and skin-related conditions in sensitized individuals. In India, several clinical studies have been undertaken to identify the fungal taxa responsible for allergic disorders, highlighting regional variability in allergenic species [4], [16].

One of the earliest significant contributions was made by Shivpuri and his team in Delhi in 1970. Their clinical investigations identified 19 fungal species—including Cladosporium herbarum, Aspergillus niger, A. fumigatus, and Alternaria alternata, as major allergens in the local population [4]. Singh et al. further expanded this work by identifying Ganoderma lucidum as a novel allergenic fungus, with skin prick tests showing positive reactions in 28.48% of patients, and whole-body extracts triggering responses in 17.44% [21].

Further clinical correlation using ELISA techniques confirmed elevated levels of IgE against Fomes pectinatis and Ganoderma, validating their allergenic potential in exposed individuals [21]. Singh and Kumar emphasized the dominant role of fungal spores in respiratory allergies and the urgent need for environmental monitoring to prevent allergen exposure [16].

In Bangalore, allergenic fungi like Mucor mucedo, Fusarium solanii, and Curvularia nigrospora were identified, while studies in Andhra Pradesh reported Aspergillus flavus, Helminthosporium, Neurospora, Candida albicans, and Cladosporium as significant allergens [16]. These regional differences underscore the geographical heterogeneity of fungal allergens across India and the importance of local monitoring to improve diagnosis and treatment.

6) Effect of Occupational Fungal Allergens:

Extensive epidemiological studies across India have revealed a high prevalence of respiratory disorders among workers exposed to fungal allergens in occupational settings such as bakeries, poultry farms, granaries, and sugar processing industries. Reports indicate that approximately 40–59% of industrial workers experience respiratory symptoms linked to fungal bioaerosol exposure [16], [20].

In bakery environments, flour dust contains high concentrations of airborne fungal spores. Workers exhibited significantly elevated levels of IgE and IgG antibodies against multiple Aspergillus species, notably A. ochraceous and A. versicolor, indicating strong allergic sensitization [5], [21]. Similarly, poultry farm workers showed heightened sensitivity to Scopulariopsis brevicaulis, supported by increased IgE antibody levels, emphasizing occupational health risks [21].

Singh and Deval reviewed multiple Indian studies, consolidating data on the occurrence and allergenic effects of fungal spores in both outdoor and indoor settings. Their findings underscore the widespread distribution of clinically relevant fungal allergens [21]. Collaborative studies led by Singh and colleagues identified several emerging allergens, including Aspergillus ochraceous, A. japonicus, Cladosporium, Alternaria alternata, Uromyces, Ustilago, Neurospora sitophila, and Sporotrichum [21].

These discoveries highlight the urgent need for improved allergen surveillance, occupational health policies, and workplace hygiene standards to mitigate long-term exposure and respiratory health risks among industrial and agricultural workers [16], [20].

7) Acromycoflora of crop fields:

Several researchers across India have conducted detailed aerobiological investigations to study plant diseases in various crops, revealing critical associations between airborne fungal spores and crop health. These studies have provided important insights into how fungal spores contribute to the initiation and spread of plant diseases in agricultural settings [6], [15].

Tilak and Babu carried out foundational work on the air spora over bajra (Pennisetum typhoideum) crops, establishing the direct relationship between the presence of pathogenic fungal spores and specific diseases affecting bajra. Their research demonstrated that fungal spores not only persist in agricultural air but also play a key role in the early development of crop diseases [15].

In studies focusing on groundnut rust, Mallaiah and Rao documented the airborne spread of urediniospores, which are responsible for rust infections in Arachis hypogaea (groundnut). Their work traced the dispersal patterns of spores and identified the environmental factors that contribute to disease outbreaks, offering predictive insights for disease management [15]. Murdhankar and Pandey expanded this research by incorporating both aerobiological and epidemiological approaches to study rust occurrence in groundnut fields across Maharashtra. Their work emphasized that the monitoring of airborne spores could provide early warnings, helping to prevent full-scale crop failures [6].

Beyond groundnut and bajra, the aeromycoflora of cereals, pulses, oilseeds, vegetables, and cash crops has been extensively studied in agro-ecological regions such as Manipur and other parts of North-East India. These investigations identified a strong correlation between meteorological conditions (such as temperature, rainfall, and humidity), crop growth stages, and the concentration of fungal spores in the field atmosphere [6], [18]. For instance, in maize fields, fungal spores were detected 4 to 5 weeks prior to the appearance of visible disease symptoms, demonstrating the potential of spore monitoring in early disease detection and intervention strategies [6], [14].

One particularly significant finding relates to the role of Alternaria alternata in leaf and stem spot diseases of sunflower crops. Scientists successfully isolated conidia—the asexual spores of A. alternata—from the air during the blooming phase of the crop, establishing the pathogen's airborne spread and its temporal alignment with critical growth periods of sunflower [14]. This confirmed that airborne fungal propagules are integral to the disease cycle and should be monitored to mitigate infection risks.

These findings collectively underscore the importance of integrating aerobiological surveillance into agricultural disease management frameworks. Monitoring airborne spores not only aids in understanding the life cycle of plant pathogens but also supports timely interventions such as targeted fungicide applications, improved crop rotation planning, and weather-based disease forecasting [6], [15].

4. CONCLUSIONS

The scientific advancements in the field of aerobiology—particularly those focused on fungal spores, have been profoundly transformative in expanding our understanding of airborne biological agents and their implications on human health, agriculture, and occupational environments in India. The comprehensive studies spanning decades have provided valuable insights into the frequency, distribution, diversity, and seasonal dynamics of airborne fungal allergens in various ecological settings [6], [22].

By examining the temporal and spatial variations of allergenic fungal spores through both outdoor and indoor studies, researchers have laid the groundwork for region-specific allergen calendars, enabling healthcare professionals to deliver more precise diagnoses and targeted treatment plans. The correlation of aerobiological data with clinical immunological profiles, such as IgE-mediated hypersensitivities, has proven indispensable in refining diagnostic tools and improving therapeutic outcomes for allergic disorders like asthma, rhinitis, and atopic dermatitis [4], [21], [23].

The integration of aerobiological monitoring with meteorological forecasting further allows for the prediction of high-risk allergen periods, thereby enhancing preventive healthcare and resource planning. In agricultural settings, the detection of airborne fungal spores ahead of disease outbreaks offers a crucial lead time for implementing disease management interventions, significantly improving crop protection strategies and reducing economic losses [6], [14], [15], [22].

One of the major outcomes of these cumulative efforts has been the identification of several clinically relevant fungal allergens across different climatic zones of India. From Aspergillus flavus and Cladosporium herbarum in urban indoor environments to Alternaria alternata and Curvularia lunata in crop fields, the allergenic landscape has been mapped with increasing precision [5], [16], [21]. In addition, novel fungal allergens such as Ganoderma lucidum and Neurospora sitophila have been discovered, highlighting the continued emergence of new health risks and the necessity for ongoing surveillance and research [21], [23].

Moreover, the role of occupational exposure to fungal spores—especially among workers in bakeries, poultry farms, granaries, and leather units—has been strongly established, emphasizing the need for improved workplace air quality standards and protective measures [20], [21]. The chronic exposure to bioaerosols in such environments not only triggers sensitization but also contributes to long-term respiratory morbidity, which is preventable with adequate environmental controls and policy-level interventions [16], [22].

Importantly, the review also points toward an urgent need for standardization of sampling protocols, inter-disciplinary collaboration, and integration of aerobiological data with public health and clinical systems. Such integrated efforts can facilitate the development of predictive models for fungal allergen load and enable real-time alert systems for susceptible individuals [6], [22].

So, the cumulative findings of aerobiological studies in India have not only enriched the global knowledge pool but have also offered regionally adapted, evidence-based strategies for disease forecasting, diagnosis, prevention, and treatment of fungal allergen-induced conditions. The advances in this field are a testament to the impact of sustained interdisciplinary research and underscore the importance of continuous monitoring, clinical validation, and translational application of aerobiological data to achieve improved health and agricultural outcomes [6], [21], [22], [23].

CONFLICT OF INTERESTS

None.

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