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Allergenic Fungal Spores, Climate Change, Urbanization, and Socioeconomic Disparities in Lithuania: A Non-Systematic Literature Review

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Summary. Socioeconomic inequality, urbanization, and climate change significantly impact environmental allergen dispersion and health outcomes. Despite global evidence, research on allergenic fungal spores in Lithuania remains limited. This study aims to explore the influence of urbanization, socioeconomic inequality, and climate change on allergenic fungal spore exposure and allergy risk in Lithuania, identifying knowledge gaps and proposing preventive strategies. A comprehensive narrative literature review was conducted, integrating case studies, observational and experimental research, clinical reports, and comparative international data. The results highlight that allergenic fungal spores, particularly *Alternaria* and *Cladosporium*, substantially impact respiratory health. Climate change is projected to extend spore seasons and intensify allergen exposure. Urban settings are associated with increased indoor fungal exposure, especially affecting low-income populations. Socioeconomic factors exacerbate health disparities due to inadequate housing conditions and limited access to healthcare. In conclusion, climate change, urbanization, and socioeconomic disparities collectively amplify the risks posed by allergenic fungal spores in Lithuania. Targeted interventions and comprehensive public health policies are necessary to mitigate the rising allergy burden.

Keywords: allergenic fungal spores, climate change, urbanization, socioeconomic disparities, Lithuania.

Alergeniškų grybų sporų, klimato kaitos, urbanizacijos ir socioekonominių skirtumų sąsajos Lietuvoje: nesisteminė literatūros apžvalga

Santrauka. Socialinė ir ekonominė nelygybė, urbanizacija ir klimato kaita reikšmingai veikia aplinkoje pasklidusių alergenų paplitimą ir sveikatos rodiklius. Nepaisant pasaulinio masto

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tyrimų, duomenų apie alergeninių grybų sporų paplitimą Lietuvoje vis dar trūksta. Šio tyrimo tikslas – ištirti urbanizacijos, socialinės ir ekonominės nelygybės bei klimato kaitos įtaką alergeninių grybų sporų poveikiui ir alergijų rizikai Lietuvoje, nustatyti žinių spragas bei pasiūlyti prevencines strategijas. Buvo atlikta išsami naratyvinė literatūros apžvalga, apimanti atvejų analizes, stebimuosius ir eksperimentinius tyrimus, klinikines ataskaitas bei tarptautinių duomenų palyginimus. Rezultatai parodė, kad alergeninės grybų sporos, ypač *Alternaria* ir *Cladosporium*, turi didelį poveikį kvėpavimo takų sveikatai. Prognozuojama, kad klimato kaita pailgins sporų sezonus ir padidins alergenų poveikio intensyvumą. Miestų aplinka didina grybelinių alergenų poveikį patalpose, ypač paveikdama žemas pajamas gaunančias gyventojų grupes. Socialiniai ir ekonominiai veiksniai dar labiau gilina sveikatos netolygumus dėl netinkamų gyvenimo sąlygų ir ribotos prieigos prie sveikatos priežiūros paslaugų. Apibendrinant galima teigti, kad klimato kaita, urbanizacija ir socialinė bei ekonominė nelygybė kartu sustiprina alergeninių grybų sporų keliamą riziką Lietuvoje. Norint sumažinti didėjančią alergijų naštą, būtinos tikslingos intervencijos ir išsamios visuomenės sveikatos politikos priemonės.

Reikšminiai žodžiai: alergeniškos grybo sporos, klimato kaita, urbanizacija, socioekonominiai skirtumai, Lietuva.

Introduction

In Europe and around the world, respiratory allergy disorders have grown in importance as a public health problem in recent decades. Airborne allergens including pollen and fungal spores are among the main environmental causes. The significance of fungal spores, especially those from species like Alternaria, Cladosporium, Aspergillus and Penicillium, is still relatively unknown despite mounting evidence of their substantial clinical impact whereas pollen allergens are well documented and closely watched in many nations. These spores can worsen diseases including asthma, allergic rhinitis and hypersensitivity pneumonitis by inducing immunoglobulin E-mediated responses. Particularly at risk are children, the elderly and people with underlying respiratory conditions [1-3]. However, Lithuania currently lacks locally created clinical data and long term aeromycological records which leaves doctors without evidence based recommendations for diagnosis, treatment or prevention [3].

Globally, environmental changes, especially urbanization and climate change, are influencing the generation, spread, and allergenicity of fungal spores. Extreme weather events, changed humidity patterns, and rising temperatures all affect the dynamics of fungal spores, which may increase the burden of allergies. Meanwhile, additional sources of indoor fungal exposure are brought about by increased urbanization particularly in overcrowded or poorly ventilated homes. Unequal exposure and health effects may result from the interaction of these environmental changes with social variables including housing quality, income level, and access to healthcare [1-3].

The issue in Lithuania is made worse by a number of overlapping tendencies. While precipitation patterns have become more varied, the mean air temperature has

increased. Warmer and wetter summers may enhance the allergenicity of spores and extend the seasons for Alternaria and Cladosporium [1, 2]. Due to rapid urbanization, many post Soviet apartment buildings and wooden country housing have poor ventilation, poor insulation and persistent dampness, which creates the favorable conditions for Aspergillus and Penicillium to grow inside [1, 4]. These hazards are made worse by socioeconomic disparities and a significant portion of Lithuanian households live in energy poverty which limits their capacity to heat, ventilate or repair their homes. These same households also face geographic and financial obstacles to receiving specialized treatment and allergy testing [1, 5].

Lithuania lacks a nationwide fungal spore monitoring network and there is still a dearth of population based data on fungal sensitization in spite of these exacerbating conditions. The purpose of this study is to compile the body of knowledge about the existence, consequences and causes of exposure to allergenic fungus spores in Lithuania, both domestically and internationally. It focuses especially on how social (socioeconomic inequality) and environmental (urbanization, climatic change) elements combine to influence risk patterns. This study lays the groundwork for future studies, monitoring programs, and public health policies targeted at lowering the health consequences associated with fungal allergies in Lithuania by outlining the state of knowledge and pointing out gaps.

Methods

Design

To combine various evidence streams (epidemiology, housing studies, policy papers, and aerobiological monitoring) that are not suitable for formal meta-analysis, a non-systematic narrative review was chosen.

Information Sources and Search Strategy

The Lithuanian Academic e-Library (eLABa), PubMed, Web of Science, Scopus, and Google Scholar were the five databases searched. The Ministry of Health, the Lithuanian Hydrometeorological Service, and the WHO/EEA archives were also searched for grey literature. The search period was 2010–2024.

Combinations of phrases pertaining to fungal spores, allergic disorders, geographic context, and environmental or socioeconomic variables were used in a comprehensive search strategy to find pertinent papers. These included outcome-related keywords like "allergy," "asthma," and "rhinitis," along with phrases like *Alternaria*, *Cladosporium*, *Aspergillus*, *Penicillium*, and "fungal spores." Geographical filters such as "Lithuania" and "Baltic" were employed to acquire region-specific data. Terms like "climate," "warming," "urbanization," "socioeconomic," and "poverty," among other environmental and social

modifiers, were included. To ensure inclusion of local sources and grey literature, equivalent search phrases in Lithuanian were also used.

Inclusion Criteria

1. Population: Research including data from Lithuania, or in the absence of Lithuanian data, from Baltic and Nordic areas with similar climates.
2. Exposure: Indoor or outdoor measurements of airborne fungal spores.
3. Modifiers: Markers of income or education, housing quality, urban/rural location, and climate characteristics.
4. Outcomes: Seasonal timing, spore concentrations, clinical outcomes for asthma or allergies, or proxy indicators (e.g., drug usage, hospitalizations).
5. Types of Studies: Case reports; government or non-governmental organization reports; experimental, observational, and modeling studies.

Exclusion Criteria

1. Research that is solely veterinary
2. Conference abstracts lacking full texts
3. Papers focused exclusively on germs or pollen

Data Extraction and Synthesis

Although no official risk-of-bias tool was used, quality indicators such as sample size, equipment calibration, and confounder control were noted. The findings were synthesized narratively, emphasizing gaps in knowledge and the quality of evidence. They were classified into three thematic domains: socioeconomic disparities, urban environment, and climatic causes.

Results and Discussion

Seasonal Patterns and Health Effects of Airborne Fungal Spores in Lithuania

When breathed in, microscopic mold particles known as allergenic fungal spores can trigger allergic reactions. *Aspergillus*, *Fusarium*, *Alternaria*, *Cladosporium*, and *Penicillium* are significant allergenic fungi in warm regions [1, 2]. With peak concentrations from July to September, these airborne spores mostly affect respiratory health in Lithuania during late summer and fall. *Alternaria* spore counts from 2005 to 2006 ranged from 3,100 in Vilnius to 9,700 in Klaipėda, with the maximum daily count recorded in August [3]. Hospitalizations rise in response to elevated *Alternaria* spore counts, which are associated with severe asthma, especially in children [1, 2, 4].

Sneezing, nasal congestion, allergic rhinitis, and severe exacerbations of asthma are among the symptoms that occur when spores reaching the deep lung regions are in-

haled [6]. Mold spore allergens significantly elicit IgE-mediated reactions; this is confirmed by fungal sensitivity testing using skin prick tests in European populations [1, 4]. In Lithuania, there is a lack of research on fungal allergies despite medical acknowledgment of the issue, resulting in limited public awareness and insufficient preventive measures [3].

Climate Change Impacts on Fungal Spores

Fungal spore generation and dissemination are greatly impacted by climate change, which is reflected in rising temperatures, elevated CO_2 levels, and altered humidity. Allergenic fungi like *Alternaria* can spread into colder climates due to longer fungal development seasons [1, 2]. Elevated temperatures have been associated with higher *Alternaria* spore loads in Central and Eastern Europe [2]. However, *Alternaria* counts were lower in Lithuania during the hot year of 2010, indicating that spore levels are influenced by other variables such as precipitation, humidity, and snow cover [1–3].

Both high and low humidity extremes influence spore development and dispersion. Wet conditions promote allergenic fungi in moist buildings, while drought favors fungi that release spores from dry plants. Lithuania's variable humidity patterns may increase the risk of allergen exposure [1].

Seasonal cycles are altered by climate change, causing spores to appear earlier and persist into autumn [1, 7]. Higher CO_2 levels enhance the development of both plants and fungi, while milder winters reduce snow's suppressive effects [7, 8]. Humidity and warmth may also increase the allergenicity of spores, exacerbating immunological reactions [1, 7].

In conclusion, Lithuania's risk of respiratory allergies and allergenic spore burdens is expected to increase due to climate change. The need for long-term spore monitoring is critical.

TABLE 1. **Influence of Climate Change Factors on Fungal Spore Dynamics in Lithuania**

Factor	Effect on Spores	Evidence in Lithuania
Temperature Increase	Extended spore seasons and increased *Alternaria* prevalence	Lower *Alternaria* counts in 2010 compared to 2005–2006 which is inconsistent data, highlighting need for surveillance
Rainfall/Humidity Changes	Droughts accelerate airborne spore release; high humidity promotes fungal growth	No specific Lithuanian studies; regional climate models suggest potential impact
Extreme Weather Events	Thunderstorms fragment spores, increasing asthma hospitalizations	No Lithuania-specific data; similar risks likely
CO_2 and Vegetation Changes	New fungal species introduced by extended growing seasons	No direct evidence; Baltic climate data suggests potential vegetation impact

Urbanization, Socioeconomic Disparities, and Fungal Spore Exposure

There is a comparable risk of increased exposure to allergenic fungal spores in urban and low-income areas. Due to degrading plant material, elevated *Alternaria* levels are typical in rural agricultural areas [2, 9]. Urban areas, on the other hand, present specific sources such as moist, poorly ventilated buildings and outdated ventilation systems frequently contaminated with *Aspergillus*, *Cladosporium*, and *Penicillium*. Widespread indoor spores were discovered in a Lithuanian school study, underscoring the poor air quality associated with insufficient ventilation and vehicle pollution in larger urban schools [10].

These hazards are further intensified by socioeconomic disparities. Older housing with leaks, inadequate insulation, overcrowding, and moisture issues is common in low-income communities, promoting the spread of fungi. In Lithuania, Soviet-era buildings with inadequate ventilation and rural wooden houses are high-risk environments for mold infestations [3]. Similar findings from American studies confirm higher fungal spore exposure in low-income housing [11].

Furthermore, contaminants like ozone and diesel exhaust exacerbate allergic reactions by sensitizing the respiratory mucosa. Urban heat islands-caused by thermally absorptive materials-can also accelerate fungal spore seasons. The combination of urban pollution and fungal spore exposure is a major public health concern, as it increases asthma emergencies, particularly during periods of high pollution [2, 9].

TABLE 2. **Urban vs. Rural Fungal Spore Exposure Patterns**

Setting	Predominant Spores	Exposure Factors	Evidence from Lithuania
Urban Indoor	*Aspergillus*, *Penicillium*, *Cladosporium*	Poor ventilation, building dampness, old construction	School classroom study showed significant indoor fungal contamination
Urban Outdoor	Mixed species, influenced by pollution	Heat islands, pollution synergy, reduced vegetation	Limited data specific to Lithuania
Rural Outdoor	Higher *Alternaria*, agricultural sources	Farming activities, natural vegetation	No comprehensive studies comparing urban rural differences
Rural Indoor	Lower levels but poor housing quality concerns	Old wooden homes, inadequate insulation	No specific data but likely similar to other European countries

Evidence and knowledge gaps in Lithuania

Lithuania lacks comprehensive long-term fungal spore monitoring and specific epidemiological data linking spore exposure to clinical allergies. Existing data show regional variations, with higher *Alternaria* spore levels in Klaipėda compared to Vilnius [3].

Public health implications

Urbanization and climate change increase fungal allergy risks in Lithuania [12]. Strengthening spore monitoring, improving indoor air quality, and expanding access to allergy testing and treatment are urgent public health priorities [8, 13].

Practical recommendation

1. **Integrate spore monitoring into the pollen network** Given the current absence of nationwide fungal spore data, Lithuania could extend its pollen stations to sample such as *Alternaria*, *Cladosporium*, and other clinically relevant genera, with additional sites placed in densely populated or economically disadvantaged districts.
2. **Strengthen indoorair regulations for public buildings** The Ministry of Health may wish to update ventilation and dampness standards for schools, hospitals, and state-subsidised housing, coupling them with routine mold inspections and enforceable remediation timelines.
3. **Support mould remediation in lowincome housing and widen allergy services** Municipalities could consider subsidy programmes or zero-interest loans for landlords and homeowners facing chronic dampness, while primary care centres might expand accessible walk-in allergy testing services in primary care and referral pathways in high-risk neighbourhoods**.**
4. **Launch culturally tailored publiceducation campaigns** Health authorities and civil society groups could deliver multilingual outreach on recognizing indoor mold, simple moisture reduction practices, and the availability of diagnostic and treatment services, using trusted channels such as local radio, schools, and community clinics.

Conclusions

In Lithuania, allergenic fungal spores already pose a significant risk to respiratory health and the combination of urbanization, climate change, and socioeconomic disparity is expected to increase that burden. However, the lack of population-based sensitization data and nationwide spore surveillance prevents accurate national-level risk assessment.

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