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Airborne mycotoxigenic fungi in Türkiye and Poland

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Abstract: There is increasing concern about exposure to airborne fungi. Research on mycotoxins shows that just as airborne fungal spores are everywhere in our environments, so too are their metabolic products. Mycotoxins with their cytotoxic, genotoxic, mutagenic, and teratogenic properties are persistent threats to human and animal health. Assessment of fungal exposure is notoriously challenging due to the numerous factors that contribute to the variation of fungal concentrations in environments. This paper reviews the homogeneity in the fungal species composition of these bioaerosols on a large geographical scale and the different drivers that shape these fungal communities which still remain unclear yet seem to be strongly governed by geographical location. Species reported from Türkiye and Poland representing *Absidia, Actinomucor, Alternaria, Aspergillus, Cladosporium, Emericella, Eupenicillium, Eurotium, Fusarium, Gibberella, Microdochium, Mucor, Paecilomyces, Penicillium, Rhizomucor, Rhizopus, Stemphylium, Talaromyces,* and *Ulocladium* are listed with nomenclatural authorities, synonyms, and references.

Key words: airborne fungi, fungal communities, mycotoxicity, fungal list, Türkiye, Poland.

Introduction

Airborne fungi are important in many aspects such as human health (such as airborne transmission of allergens or pathogens to humans), agricultural (fungi may cause disease in cultivated plants and may reach another field by air, agricultural machines, animals, insects, humans, etc), veterinary, potential to cause problems in food production, food spoilage by fungi, the spread of fungi in nature, damage to historically important structures, decay of organic materials in nature. Also Tang & al. [2022] wrote that "bioaerosols can act as nuclei for cloud droplets and ice crystals that influence precipitation formation". The number and types of fungi in 1 m^3 indoor and outdoor air are very variable and this variability depends on many factors. These factors include wind, temperature, vegetation, humidity, precipitation, altitude, pH, sunlight, presence of organic materials suitable for the growth of fungi in the environment, human and animal activities, agricultural activities, season, day and night &(humidity increase in the morning triggers the release of fungal spores into the air), soil type and moisture station of the soil, the main living environment of fungi in nature is soil; moist of soil, presence of organic substances and suitable temperature increase fungal activities. Fungi in the soil can pass into the air in various ways, especially through wind [Atlas & Bartha 1998, Asan & Ekmekci 1994, Asan & al. 2002, Shelton & al. 2002, YuLong & al. 2021, Sun & al. 2022, Li & al. 2022]. According to YuLong & al. [2021], there are 1200 bacteria and Actinomycetes and 40,000 fungal species in the atmosphere.

There are various studies on fungal checklists in the world and in Turkey [Asan 2004, 2011, 2015, Asan & al. 2016, Sesli & al., 2020, Voronin & al. 2021, Anees-Hill & al. 2022]. In a review study including 5 research results from Türkiye and covering Europe [Anees-Hill & al. 2022], it was stated that *Alternaria* and *Cladosporium* species were mostly encountered; in some publications only genus records are given, e.g. Sevindik & al. (2022); Ozdilek & al. (2023); Palaz & al. (2023). Sesli & al. [2020] published a checklist of all registered fungi from Türkiye. Here, unique Turkish scientific names have also been given to all taxa (phylum, family, genus, species) in the records (for the Turkish scientific names [Sesli & al. 2020], also mentioned Turkish scientific names are used in this study. It is stated from which region or part of Türkiye the species given in this work were recorded, but whether the fungal species was air, soil, food, etc. information with which it is isolated, habitats are not given; but the host names of the fungi reported from the plants were given. In this article, a list of recorded in literature and airborne fungi from Türkiye and Poland is given. Many researches on airborne fungi in Türkiye have been discussed in this paper; in addition, the study of Asan & Giray [2019] can be consulted for the historical development of this subject in Türkiye.

In our study, considering the literature reporting airborne fungi in Türkiye and Poland, which are geographically distant from each other, the list of airborne fungi in both countries has been given and comparisons have been made in terms of airborne fungi in these two countries.

Materials and Methods

In our study, outcomes reporting airborne mycotoxigen and mycotic from Türkiye and Poland were taken into account. To the best of our knowledge this paper provies all accessible references considering the undertaken topic. The literatures that gave only fungal genus and their species records were not taken into account. In other words, although there are studies of airborne fungi in some publications [Baysal & al. 2019, Onoglu & al. 2011, Yoltas & al. 2009], the fungal genus records in such publications could not be included in our article, since no records were given at the fungal species. Current names of fungal genera and species are in bold & Italics according to the <www.indexfungorum.org> and <mycobank.org> websites.

For the isolation of fungi from air, passive methods (*such as the gravity based petri plate method*) and active methods (*such as drawing a certain amount of air over a certain period of time with a sampler device*) are used. For details of fungal isolation methods from air, it can be see Pinherio and Viegas (2016).

Results: Records from Türkiye

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Absidia ramosa (Zopf) Lendn., Mat. Fl. Crypt. 3(1): 144 (1908) (***Lichtheimia ramosa*** (Zopf) Vuill., Bull. Soc. Mycol. 19: 126 (1903)) (TSN: Lamaküf). [Ciftci 2007, Acar 2007].

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Absidia spinosa Lendn., Bull. Herb. Boissier, 7: 250 (1907) (TSN: Diken böcekçi) [Colakoglu 2003].

Actinomucor Schostak., Ber. Dt. Bot. Ges. 16: 155 (1898) (TSN: Işıkküfü).

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Discussion

Although fungi are ubiquitous, not all the fungi grow in the same environment. The composition and concentration of airborne fungi are strongly governed by geographical location, which has been shown also in this paper, as well as influenced by seasonality [Marynowski & al. 2020]. The seasonality is contingent on several interplaying factors, including meteorological conditions, local vegetation sources, and anthropological activities such as agriculture and large-scale composting [Grinn-Gofroń & al. 2020]. One of the most mycotoxigenic genera is *Fusarium.* The severity of human diseases and accumulation of associated mycotoxins synthesized by these group of fungi is strongly driven by meteorological factors. This hypothesis seems to be justified in our studies, reporting more species of *Fusarium* in Turkish environement (24 species), as well indoor as outdoor than in Poland (19 species). In general, the coincidence of wet and warm environments is favourable to increase *Fusarium* sp. inoculum. There are 3 types of climate in Türkiye: Mediterranean, Continental and Oceanic. The greatest part of the country, including much of the montane area, comes under the influence of various types of Mediterranean climate [Unal & al. 2003], which is principally characterized by warm summers and wet winters. Most of the reports presented in our studies come from these parts of Türkiye. The most important mycotoxins of the *Fusarium* genus are deoxynivalenol (DON), T-2 toxin, and zearalenone (ZEN). Other *Fusarium* toxins include fumonisins, fusarins, enniatins, and beauvericin. The effects of global warming, such as increasing temperature and rainfall levels,play a vital role in the infestation of pathogenic fungi. Several studies have demonstrated that these effects induce enhanced colonisation and toxicogenic potency of fungi from the *Fusarium* genus [Bernhoft & al. 2012].

Airborne fungi may be found in all regions and their distribution depends on very different criteria such as temperature, moisture, vegetation, human activities, and type of soil, etc [Asan & al 2002]. Therefore, it is difficult to say which fungal species are characteristic for which country. However, it is possible to claim that *Cladosporium herbarum, Aspergillus fumigatus, A. niger, A. flavus, A. versicolor* and *Penicillium chrysogenum* are common in both Türkiye and Poland. The frequent reporting of *A. niger, A. flavus and A. fumigatus* in both countries are coherent with their high occurrence levels in indoor and outdoor environement. The inhalation of airborne *A. flavus* or contact with the invasive fungal growth on surfaces and dust may cause aspergillosis in humans and animals, a disease often lethal to immunocompromised people [Klich 2007]. Moreover *A. flavus* is the main producer of harmful secondery metabolites-aflatoxin. There are two general forms of the disease caused by exposure to aflatoxin, aflatoxicosis. Acute aflatoxicosis results in death. Chronic aflatoxicosis causes cancer, with the liver as the primary target organ, immune suppression, teratogenicity and other symptoms. There is also some evidence that respiratory exposure to aflatoxin increases the occurrence of respiratory and other cancers [Bennett & Klich, 2003]. *A. fumigatus* as a worldwide distributed saprophytic fungus and an opportunistic pathogen for human and animals is of great importance to public health because it is capable of producing tremorgenic mycotoxins and inducing neurological syndromes. pathogenicity depends not only on the hosts immune status but also on the virulence of the fungal strain, which is not given by a single factor of essential virulence, but is under polygenetic control. It is known that *A. fumigatus* produces several immunosuppressive mycotoxins including gliotoxin, fumagillin, helvolic acid, fumitoxins, fumiclavines A and C, fumitremorgins, verruculogen, among others. All these mycotoxins inhibit the function of leukocytes in terms of migration, superoxide production and fungicidal activity. Among them, fumagillin has the ability to inhibit endothelial cell proliferation acting as an anti-angiogenic factor, and suppress neutrophil function [Fallon & al. 2010]. In case of *A. niger*, up to 6% strains synthesise the mycotoxin ochratoxin A, causes carcinogenic changes, and its degree of production depends on environmental factors, such as the substrate or cultivation medium type [Šimonovičová & al. 2021].

Many studies demonstrated that most common airborne fungal genera are *Alternaria*, *Cladosporium* and *Penicillium* and this situation was strongly influenced by temperature. Increasing temperature may result in prolonged fungal spore seasons. When this factor increases, the concentrations of this form-genus also increases [Anees-Hill & al. 2022]. Considering the fact, that avarage temperature in Poland and Türkiye vary depending on the month from several to over dozen degrees, association of quantity and species contents within both mentioned genera is closely related. Within *Alternaria* genus, *A. alternata* was the most frequently reported species, both in Türkiye and Poland. This species produces more than 70 phytotoxins, but a small proportion of them have been chemically characterised and reported to act as mycotoxins to humans and animals. Some toxins such as alternariol, alternariol monomethyl ether, tenuazonic acid and altertoxins are described to induce harmful effects in animals, including fetotoxic, teratogenic mutagenic and clastogenic effects [Chen & al. 2021]. The most dangerous mycotoxins are produced by *Penicillium* spp. including: PAT (patulin), ROC (roquefortine C), MPA (mycophenolic acid) and CPA (cyclopiazonic acid). PAT, produced by many species of *Penicillium* is involved in various health disorders, causing tremors, paralysis, and death. CPA exposure can result in tremors, liver, kidney, and gastrointestinal tract damage [Habschied & al. 2021]. The main producer of ROC (roquefortine C) is *P. roqueforti*, reported in both countries. This species also produces PR-toxin (Penicillin Roquefort toxin) and MPA (mycophenolic acid). All mentioned mycotoxins cause different kind of toxicosis showing symptoms like: paralysis, tremors, and convulsions [Nielsen & al. 2006].

Usually attention is focused on the most known and common airborne fungi i.e. *Alternaria, Aspergillus, Cladosporium* or *Penicillium*, but special comment requires *Stemphylium* spp. reported both in Poland and Türkiye. Since the Public Health Agency of Canada (PHAC) of the Government of Canada listed *Stemphylium* spp. in Risk Group 2 under the authority of the Human Pathogens and Toxins Act [Government of Canada 2009], their treatment as potential human and animal pathogens is warranted based on their potential impact on the health. One of the species recorded in Türkiye was *Stemphylium vesicarium* [Polat & al. 2012, Demirel & al. 2017]. Four secondary metabolites that appear to be hosts of specific toxins are produced by *S. vesicarium*: stemphylin, stemphyperylenol, stemphyloxin, and stemphol [Andersen & al. 1995], and some of these plant toxins are being examined as potential treatments for human cancer [Laidou & al. 2001].

The recent COVID-19 outbreak led to a global health emergency affecting millions of people worldwide. A number of studies documented interaction between SARS-CoV2 and airborne fungi [Divakar 2021, Lai & Yu 2021, Chung & al. 2022]. Aspergillosis is an important cause of morbidity and mortality among immunocompromised individuals with a broad spectrum of diseases ranging from noninvasive to invasive, severe, and rapidly fatal infections [Cadena & al. 2016, Salmanton-Garcia & al. 2020]. The increased incidence of aspergillosis among COVID-19 patients is mostly contributed by *Aspergillus fumigatus*, one of the most widely reported species both in Poland and Türkiye. Besides *A. fumigatus,* many other fungi such as *Fusarium moniliforme,* and *Mucor* sp, are known to be transmitted through bioaerosols and caused various respiratory abnormalities, hypersensitivity and system organ infection [Jung & al. 2009]. Mucormycosis is caused by fungi belonging to the order *Mucorales.* The term “Black Fungus” has been widely applied to human pathogenic *Mucorales* in many countries. They mainly infect the sinuses, brain, lungs, stomach, intestines, and skin. While this has been considered a rare disease, thousands of cases have been reported during the COVID-19 pandemic [Prakash & al. 2019]. Besides enormous diversity of airborne fungi functions’, which have been well recognized and discussed in many papers, recently they have been implicated also in terms of contributing to Sars-CoV2 transmission. Due to increased importance of airborne fungi in Covid-19 disease, it is necessary to explore the pathogenic mechanism of this combination, therefore significant efforts of the global scientific community should be undertaken in understanding this phenomenon.

Conclusion

This review allowed us to confirm that the composition and concentration of airborne fungi are strongly governed by geographical location, as well as influenced by seasonality. The toxigenic potentials of the mycotoxigenic fungi threats to human and animal health, and their negative role becomes more and more crucial due to they have been implicated also in terms of contributing to SARS-CoV2 transmission and to increase the severity of COVID-19. Therefore, a wider spatial and temporal sampling, which covers diverse agro-ecological zones and year-to-year climatic variations, could also be undertaken to fully comprehend what we are up against in terms of mycotoxigenic fungi. Good agronomic practice can be the first-line defense against fungal diseases and the subsequent production of mycotoxins. Moreover, a more thorough molecular differentiation method, such as multi-locus analysis or more extended like metagenomic sequencing should be employed in future works to better identify genetically mycotoxigenic species.

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