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Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

REVIEW ARTICLE BIOSCIENCE RESEARCH, 2021 18(1): 788-794. **OPEN ACCESS**

Bioaerosols from indoor environment: Seasonal variation and impact on human health

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Indoor air environments contain a complex mixture of bioaerosols containing bacteria, protozoans, viruses possibly including SARS CoV-2 causing COVID-19, and their by-products as well such as endotoxins, mycotoxins, and volatile microbial organic compounds. Bioaerosols are forms of air particles, present mostly in the indoor air that humans inhale. Therefore, the indoor environment is crucial components causing various health-related problems. Almost 40% of individuals spent their quality time at home and the remaining 60 to 70% of individuals spent their day in the workplace. There is a lack of awareness about bioaerosols of the indoor environment and their contribution towards the spread of various infections. This review presents the trend of various elements of bioaerosols in indoor air and their association with pulmonary and other diseases due to indoor air pollution. Recently, the pandemic outbreak of COVID-19 has alerted us about the importance of bioaerosol research. Hence, the characterizations of bioaerosols including seasonal variation are necessary for its associated risk factor, prevention, and impact on human health.

Keywords: Bioaerosol; indoor environment; bacteria; fungi; virus

INTRODUCTION

Indoor air value is considerably affecting the health of people who inhale 10m^3 of the air in daily life and spend most of their lives inside the home. The air inhaled by humans is mostly inhabited with various types of microorganisms, which is so-called bioaerosols. The likely sources of bioaerosols of indoor air includes dust, humidifiers, some stored equipment in the buildings, and the air inflowing from the air condition. Bioaerosols can cause a wide range of unpleasant effects, that causes the respiratory allergy, bronchial asthma, and various type of contagious diseases, which costs lungs, intestines, kidneys, the central nervous system disorder, and may even causes demise in significant numbers of people (Humbal et al., 2018). In the whole world, it is estimated that millions of people die every year due to bad air quality (Haryanto and Franklin, 2011). Different viral diseases can also spread to humans through bioaerosols. Standard air quality has been a matter of considerable attention in the developed world; however, very few detailed studies have been published on the air quality of the indoor environment (Saleem et al., 2020). It should be focused on countries facing other burning health issues that contend for both resources and manpower. However, only limited data are available on diseases associated with indoor bioaerosols (El-Sharkawy and Noweir, 2014).

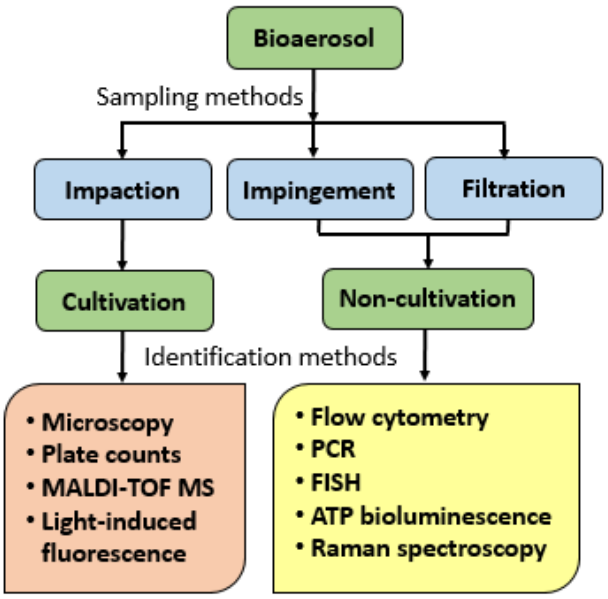

Figure 1: Bioaerosol assessment methods and identification techniques (MALDI-TOF MS, Matrix assisted laser desorption ionization-time of flight mass spectrometry; PCR, Polymerase chain reaction; FISH, Fluorescence in situ hybridization)

More specifically, there is limited specific data available on seasonal dependent bioaerosols and their impact on human health.

Sources and components of bioaerosols from indoor area

A detailed analysis of indoor environment, including the seasonal and circadian concentration of bioaerosol, is crucial as it may help in defining the etiology of diseases for inhabitants (Horner et al 2008). The interpretation of indoor bioaerosols levels is complex. This is because indoor bioaerosols concentration may show a mere quantitatively variable picture of outdoor bioaerosols content, or may also have marked differences in bioaerosols types and concentration due to some endogenous sources (Shelton et al 2002). There are diverse sources of indoor environments like home, libraries, archive storage facilities, cinema halls, hospital wards, bakeries, cattle sheds, noodle manufacturing units, museums that have been surveyed to analyze patients' specific residential as well as workplace exposure (Zielinska et al., 2008; Wiszniewska et al., 2009).

Bioaerosols are airborne particulate matter of biological origin that are composed of bacteria, fungi, viruses, allergens, insect emanations, detritus, etc. They are ubiquitous in nature and typically exist in two forms *viz*. viable and non-viable. The viable form includes bacteria, viruses, and fungi, whereas the non-viable consists of endotoxins and proteins (Turaga et al., 2012). The size of the particle in bioaerosol typically ranges from 0.3 to 100 µm in diameter. Bioaerosols, which tend to be extremely small, generally remain suspended in the air over a long period, thus posing a greater risk of airborne infection, whereas larger particles tend to deposit on the surface. A number of aerobiological and clinico-immunologic studies have been undertaken on the identification of clinically important bioaerosols in different parts of the world (Kim 2018; Kausar et al., 2007, 2016).

Bacteria

The literatures suggested that the microbial isolates from indoor environment included various species of bacteria including *Neisseria* sp., *Streptococcus pyogenes, Staphylococcus aureus*, *Bacillus* sp. and *Micrococcus* sp. (Hayleeyesus and Manaye, 2014). Mostly the isolated bacteria are Gram-positive cocci, commonly linked with mucosa and skin of humans, thus signifying that the leading bacterial contamination suspended in the indoor environment originates from human presence. A study revealed that *Staphylococcus aureus* was isolated from the general and emergency wards of hospitals (Kunwar et al., 2019). Along with this, there are other species of bacteria which were

isolated from different wards of the hospital includes coagulase-negative *Staphylococci*, *Micrococcus* spp., *E. coli*, *Pseudomonas* spp., *Proteus* spp., *Streptococcus* spp., and *Bacillus* spp. (Kunwar et al., 2019; Siddiqui et al., 2017).

Fungi

Fungi are eukaryotes, representing a separate entity within living organisms with more than ten thousand species. It is filamentous and mostly spore-bearing organisms. They mainly dispersed as sexual spores or asexual conidia, forming common components of aerospora. The size of fungal spores ranges from 2-3 µm (*Penicillium* and *Aspergillus*) to 160 µm (*Helmintho sporium*) (Ingold, 2012). The number of airborne fungal conidia fluctuate widely in indoor and outdoor environment ranging from 10^2-10^6 spores per cubic meter of air (Vermani et al., 2010). Among all the types of bioaerosol suspended in the air, fungal spores form its most predominant constituent (Vermani et al., 2010). *Penicillium*, *Aspergillus*, *Alternaria*, *Cladosporium,* and yeasts are major fungal types present in indoor environment (Ziaee et al., 2017). Interestingly, the concentration of various species of *Aspergillus* was higher in urban homes as compared to suburban homes in Argentina (Basilico et al., 2017). *Penicillium*, *Cladosporium,* and *Aspergillus* were isolated from 93%, 77%, and 60% of 190 homes, respectively, in Paris, France (Dassonville et al 2008). Multivariate analysis revealed that outdoor fungal concentration was the best predictor for the variability of indoor total airborne fungal concentration (Dassonville et al., 2008).

Viruses

Human activities like coughing, sneezing, talking, laughing may involve spreading thousands of millions of airborne viruses in the indoor environment through droplets (Weber and Stilianakis, 2008). Corona viruses, belonging to *Coronaviridae* family, are a group of related viruses that are known to infect humans and various animals. In humans, coronaviruses can cause serious respiratory problems like pneumonia and lung failure (Ahn et al., 2020). These can range from mild to lethal. Mild illness includes common cold, which is caused by around 15-30% of human coronaviruses, whereas more varieties that are lethal are known to cause SARS-CoV that was originated from bats in China in 2002 and the Middle East respiratory syndrome coronavirus (MERS-CoV) which occurred in 2012 in the Middle East. These are enveloped viruses with single-stranded RNA genome (Chan et al., 2020). They have characteristic club-shaped spikes that protrude from their surface. On 31st Dec 2019, a case of pneumonia with an unknown cause has been reported in Wuhan city to the WHO Country Office in China (Chan et al., 2020). Subsequent investigations identified it as a novel coronavirus, now known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Within a few months of the confirmed first report, the virus has been spread from Wuhan to other parts of China and Worldwide, reaching a pandemic level. This causes an outbreak as secondary transmissions are occurring, and the speed of transmission is accelerating day by day. This situation leads to rising concerns about community infections (Lei and Grammer, 2018). Untreated COVID-19 can cause severe health problems, which include short and long-term sequelae. We need effective treatment on time as well as tests that will make it possible to check the spread of disease to the other people and prevent or minimize the complications of chronic infection.

Allergens

An antigen that stimulates hypersensitivity by an immunologic mechanism in a genetically predisposed individual is referred to as an allergen. Allergens are usually proteins/ glycoproteins or chemically complex low molecular weight substances. According to the routes of exposure, allergens have been classified into four groups *viz*. inhalants (e.g. pollen and fungal spores), ingestants (e.g. food articles and additives), injectants (e.g. insect bites and stings, injected medicines), and contactants (e.g. cosmetics). Among these, inhaled environmental allergens (aeroallergens) form the most important group causing allergic respiratory diseases. The common inhalant allergens include pollen, fungal spores and associated fragments, house dust, mites, animal danders, insect emanations, detritus etc (Kausar, 2018).

Insect emanations and detritus

There are wide varieties of insects in our environment, and exposure to emanations and detritus of these insects may lead to respiratory allergies in some genetically predisposed individuals. Insect species belonging to at least 12 different orders have been implicated in the causation of inhalant allergy in man (Kausar, 2007; 2018). Mosquito, one of the biting insects, has been reported to be an important inhalant allergen from India and some other countries (Kausar et al

2007). Gupta and coworkers (1990) conducted studies on different genera of mosquitoes *viz*. *Aedes aegypiti, Anopheles stephensi* and *Culex quinquefasciatus*. Results indicated the presence of both cross-reacting and shared allergenic components among the three species of mosquitoes. It is reported that the proteins, such as D7 and apyrase protein, are important allergens in *Aedes* and related mosquitoes (Cantillo, 2014). Kausar et al (2007) reported mosquitoes-derived allergens as sources of inhalant allergens in patients suffering from respiratory allergy.

Assessment methods of bioaerosols

Bioaerosols eminence is a significant basis that needs to be addressed when evaluating enclosed work environments to provide a healthy atmosphere. Some of the important methods or techniques used for bioaerosol isolation and identification are summarized in figure 1. Bioaerosol isolation may be carried out by impactors, impingers and filtration samplers; however, identification performed by microscopy, FISH, cytometry, PCR, ATP-bioluminescence and spectroscopic methods.

Seasonal variation and indoor air quality

The U.S. EPA (2020) reported that climate change influences indoor environmental quality. The significant climatic factors that influence indoor air quality of naturally ventilated buildings includes speed and direction of the wind, temperature, relative humidity, precipitation and solar radiation (Chithra and Shiva, 2018). Many studies revealed that the average concentration of various pollutants is high in the winter season that may be due to the lowest ventilation capability (Elbayoumi et al., 2014). The seasonal variations affect indoor air pollutants in schools also as suggested by various researchers through their studies. They found that in the classrooms, the pollutant level were high during winter season in comparison to summer (Elbayoumi et al., 2014). Conversely, one study concluded that in the classrooms, the indoor bacterial concentrations are significantly high in the summer than the winter (Sohn, 2009). The study conducted in Ankara (Turkey) by Mentese and coworkers, reported that the level of bioaerosol were found higher in the winter season in comparison to summer (Mentese et al., 2012). In another study on airborne fungi in southern Indian region suggested increased concentration of *Aspergillus fumigatus* and *Cladosporium cladosporioides* during monsoon. However, the concentration of *Alternaria alternata* elevated during winter in indoor environment (Priyamvada et al., 2017). LeBouf and associates (2008) also demonstrated bioaerosol variability in indoor environment during the various seasons. They found that bioaerosol ranged from 7-36% in summer and 24-212% during winter. The concentration of some airborne fungi, including *Aspergillus* and *Cladosporium* spp. declines during the dry season and rises during rainy and cold weathers, as reported by Ponce-Caballero et al (2013). They found that the level of indoor airborne fungi during cold season was 1653 CFU/m^3. However, during dry and rainy period it was 125 and 1326 CFU/m^3, respectively (Ponce-Caballero et al 2013). In contrast, Taylor and coworkers (2014) reported that in office building of Adelaide (Australia) the culturable airborne fungi, most commonly *Penicillium, Aspergillus, Cladosporium* and *Alternaria*, were higher in summer than the winter. One of the studies on adenovirus demonstrate that the concentrations were significantly higher in winter than in spring (Moon et al., 2014). These literatures concluded that the indoor bioaerosol concentration fluctuates not only due to variation in season but also due to other climatic factors. Therefore, we can conclude that there is a need for more research on indoor air quality and its relation to different seasons.

Effects of bioaerosols on human health

Quality of indoor air and presence of various substances in the air has a great impact on human health, affecting their respiratory, immune system as well as gastrointestinal system after being exposed to the vast majority of toxin present in indoor and outdoor air. Some studies concluded that there is increased prevalence of asthma in children living or getting school near an intensive farm (Raoult et al., 2005). Industrial bioaerosols like cotton processing and waste/garbage recycling are known to increase the production of cytokines and are responsible for the dysfunction of alveoli. Another study by Kaji and associates (2014) conveyed a relationship of bioaerosols and increased risk of non-atopic respiratory disorders. The study shows the presence of fungal spores and other endotoxins in bioaerosol as a risk factor for asthma and allergic rhinitis. Positive association between occupational exposure to bioaerosols and inflammation of repertory bronchi is shown by some studies and also show a strong link between chronic bronchitis and presence of bacterial toxin in aerosols (Eduard et al., 2004). However, some studies deny these positive linkages (Radon et al., 2001). The majority of studies reported to decline

the FEV1 in individuals being exposed to bioaerosols and have respiratory symptoms like cough, shortness of breath, and rhinorrhea. Analysis of their respiratory swabs and broncho-alveolar lavage revealed increased production of inflammatory mediators, cytokines milieu, and increased prostaglandin secretions due to occupational exposure to bioaerosols (Sahlander et al., 2010).

Prevention and control of bioaerosols

Poor indoor quality of the building is one of the recent areas of debate because it has a great impact on human health and on quality of life. One of the most common presenting symptoms is headache in old housing and buildings due to the presence of airborne microbes, improper ventilation and temperature, inadequate glare, sunlight, and noisy places (Raw et al., 2000). To prevent long term health hazard by indoor air pollution there is need to discuss the infra structural and design during any house and building design. Also, there is a need to carry out some essential environmental parameters measurements in new and old buildings, even in educational institutes and tertiary care facilities annually to improve indoor and outdoor air quality. Due to unhealthy indoor air quality humans may have some common symptoms like dry eyes, headache, scaly skin and nausea and fatigue documented by some studies. To enhance the healthy life and provision of comfort to the industrial and factory workers, indoor environments have been precise and have effective heating, ventilating and air-conditioning (HVAC) systems and also proper analysis of temperature, humidity and air quality inside the building. There is a need to develop effective and measurable systems that employ air filtration, and waste drainage, which may collect organic dust or microorganisms that become an essential component of bioaerosols. Some preventive measures include the adequate design of the building of ventilation and air filtration and distribution and proper operation and maintenance strategies. To address the contaminated indoor air or to restrict the microbial growth, it is needed for the provision of sufficient fresh air ventilation.

CONCLUSION

Indoor air quality affects human's life severely and brings life-threatening diseases among the general population together leading to high mortality. Bioaerosol contains pathogenic agents such as bacteria, fungi, viruses and other infectious materials, health hazards and toxins. Bioaerosol causes a variety of diseases like disorders of lungs, intestines, kidneys, the central nervous system disorder, and affects humans' normal daily life and severe illness. Current scenario is predicting the poor air quality over the world, especially the developed and developing countries are providing the opportunity for the flourishing of microbial agents, causing severe lethal diseases. The recent outbreak of a bioaerosol named COVID-19 all over the world poses a serious threat to human health. It is very important to maintain the air quality indoor and assessment of bioaerosols needed to avoid the health risk among the general population. Maintaining good air quality would be important to reduce the health risk and better health of humans.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEGEMENT

This research has been funded by Scientific Research Deanship, University of Hail, Saudi Arabia through the project number RG-191228.

AUTHOR CONTRIBUTIONS

MAK, FK and MS wrote first draft of the manuscript. SA, SMAS and TG collected data and literature. AH reviewed the manuscript. MK contributed in literature search and finalized the manuscript. All authors read and approved the final version of the manuscript.

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