Journal of Aerosol Science 106 (2017) 93–99

Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

Evaluation of aerosolization characteristics of biocontaminated particles from flood-damaged housing materials

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ARTICLE INFO

Keywords:
Biocontaminant
Aerosolization
Source release
Flood
(1→3)-β-*D*-glucan
Bioaerosol

ABSTRACT

The purpose of this study was to examine the aerosolization characteristics of biocontaminated particles, including particle release behavior and the concentrations of culturable fungi and (1→3)-β-*D*-glucan from four flood-affected floor and bedding materials. We applied an aerosolization process using multiple air jets, then measured the particles aerosolized from biocontaminated materials in real time using an optical particle counter, while simultaneously collecting particles in a BioSampler. The total count of particles released over 10 min was highest from linoleum (25,503 particles/cm^2), followed by rugs (1562 particles/cm^2), carpets (508 particles/cm^2), and pillows (24 particles/cm^2). Linoleum, which has a hard surface, released particles the fastest (< 6 s) among the test materials. During fractional particle concentration analysis, the portion of submicron particles between 0.3 and 1.0 μm was 66.1% (linoleum) – 77% (carpet) of the total particle concentration. Additionally, based on biological assays of the collected particles, the levels of culturable fungi and (1→3)-β-*D*-glucan in the four materials ranged from undetectable (linoleum; lower limit = 0.2 CFU/cm^2) to 0.83 CFU/cm^2 (rug) and from 0.84 (carpet) to 3.26 ng/cm^2 (rug), respectively. We suggest that these results are helpful for further understanding of the aerosolization characteristics of biocontaminated particles from flood-affected materials, with benefits for the safe restoration of flood-damaged homes.

1. Introduction

Over the last decade (2004–2013), flooding has accounted for 79% of all natural disasters in the Republic of Korea, causing approximately 7.32 billion US dollars in damage during 174 flood disasters (MPSS, 2014). The frequency of flooding has increased by 60% over the last 20 years (1991–2010) due to a changing climate and increased urbanization (KMA, 2011).

Standing water and sediment left behind in flooded areas can create a breeding ground for various microorganisms including fungi, bacteria, and viruses. These microbes thrive on nutrients provided by housing materials and accumulated soil. Abraham and Wenderoth (2005) found that mud enriched with facultative microorganisms remained after a flood in Germany had receded. High bacterial cell counts have been observed in the cellars of flooded houses, on playgrounds, and on streets, where they form a pathogenic reservoir.

After flooding, high levels of moisture on housing materials can lead to growth of fungi which have been associated with allergic respiratory diseases, particularly asthma (Douwes, Thorne, Pearce, & Heederik, 2003; Taylor, Lai, Davies, Clifton, Ridley, &

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http://dx.doi.org/10.1016/j.jaerosci.2017.01.006
Received 8 September 2016; Received in revised form 13 December 2016; Accepted 23 January 2017
Available online 24 January 2017
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Biddulph, 2011). Viable fungi can produce aerosolized spores, fragments, toxins, and volatile organic compounds during germination (Green, Mitakakis, & Tovey, 2003) and may cause mycotic infections in immunocompromised individuals (Burge, 2001; Eduard, 2003). An association between (1→3)-β-*D*-glucan (a polyglucose molecule comprising up to 60% of the cell wall in most fungal taxa) in indoor environments and symptoms such as dry cough, phlegmy cough, hoarseness, and atopy has been reported (Adhikari et al., 2011; Douwes, 2005; Rylander, 1999; Rylander, Norrhall, Engdahl, Tunsater, & Holt, 1998; Tischer et al., 2011). Wan, Li, Guo, Rylander, and Lin (1999) reported that (1→3)-β-*D*-glucan potentiated ovalbumin-induced eosinophilia in the airways in a mouse model. Fogelmark, Thorn and Rylander (2001) investigated the lung cellular inflammatory response in Guinea pigs after they inhaled (1→3)-β-*D*-glucan and found that (1→3)-β-*D*-glucan caused an eosinophil-dominated inflammatory response in the airway epithelium. The aerosolization of fungi and associated toxic substances including endotoxins, and (1→3)-β-*D*-glucan from growth surfaces is driven by energy from external sources and influenced by various environmental factors.

In general, air currents are the most prevalent mechanism for formation of indoor bioaerosols (Gregory, 1973; Madelin, 1994). Microorganisms can become airborne and inhaled, which may increase the incidence of lung disease, among other health effects. After floodwaters recede, residents clean and repair their properties, and laborers work on construction and housing maintenance. These groups are often at risk for inhalation exposure to dust containing microbes and other biocontaminants during repair and removal of flood-damaged infrastructure and housing materials (Bloom, Grimsley, Pehrson, Lewis, & Larsson, 2009; Riggs et al., 2008). The World Health Organization (WHO, 2009) recommends avoiding or minimizing persistent dampness and microbial growth on interior surfaces and in building structures, as they may lead to adverse health effects. Studies on flooded properties have shown an association between respiratory problems and water-damaged homes (Dales, Zwanenburg, Burnett, & Franklin, 1991; Ross et al., 2000). This suggests that microbial growth is a significant environmental health challenge after major floods in populated urban areas. Chew et al. (2006) investigated three homes in New Orleans after Hurricane Katrina (August 2005) and reported that concentrations of airborne culturable fungi before renovation ranged from 22×10^3 to 515×10^3 colony forming units (CFUs)/m^3 of air. In a 20-home study in the same flood area, Rao et al. (2007) measured 280×10^3 m^{-3} spores for airborne fungi and 1.6 μg/m^3 for airborne (1→3, 1→6)-β-*D*-glucan.

Conventionally, airborne microorganisms are assessed by sampling air over specific time intervals. However, because the release of microorganisms from contaminated surfaces does not necessarily occur during air sampling (Horner, 2003), direct source evaluation techniques (e.g., swab, tape, and vacuum sampling) have been used to assess the aerosolization potential of microorganisms growing on surfaces in indoor environments. In particular, aggressive sampling using multiple air jets and a suction pump may more adequately represent the potential risk of exposure to aerosolized microorganisms from a contaminated material. For example, the Fungal Spore Source Strength Tester (FSSST), developed as an inexpensive and portable device, was found suitable for aggressive sampling of potentially aerosolizable fungal spores from mold-contaminated sources (Grinshpun et al., 2002; Niemeier, Sivasubramani, Reponen & Grinshpun, 2006; Seo, Reponen, Levin, Borchelt, & Grinshpun, 2008; Sivasubramani, Niemeier, Reponen, & Grinshpun, 2004). Adhikari et al. (2009, 2010) used FSSST to determine the aerosolization characteristics of moisture-related microbiological hazards (culturable and total fungi, (1→3)-β-*D*-glucan, and endotoxins) from various housing materials in New Orleans after Hurricane Katrina. Although direct source evaluation techniques can overestimate the inhalation exposure risk to aerosolized microbial biocontaminants from flood-affected material, the results of aggressive sampling are useful to assess the aerosolization potential of microbial sources, which allows the prediction of maximum aerosol concentration for each microbial contaminant in each flood-affected home.

Previous studies have focused mainly on sampling and quantifying aerosolized microorganisms or biomarkers. Although there are significant public health concerns about aerosolization of airborne microorganisms and the associated respiratory health effects, current scientific knowledge concerning the aerosolization of microorganisms from flood-affected building materials is insufficient. Total release and the size fraction of aerosolizable biocontaminants from contaminated material can vary with release time as well as a kind of materials and environmental condition. Therefore, more information on the release of microorganisms from biocontaminated material is needed to assess the risks of exposure to mold or bacteria and to understand the associated health effects. The purposes of this study were (i) to characterize aerosolization of particles from four different flood-affected household materials using a real-time optical particle counter (OPC; ranging from 0.3–20 μm, 6-s intervals) and (ii) to determine the aerosolization characteristics of culturable fungi and the fungal biomarker (1→3)-β-*D*-glucan.

2. Materials and methods

2.1. Collection of flood-affected materials

After a period of localized heavy rain (30 June–5 July 2016), samples of four types of floor and bedding material (linoleum, rug, carpet, and pillow) were collected from three flood-affected homes in an urban area of Seoul, Republic of Korea. The homes were determined to have moisture incursion and thus were expected to have fungal and bacterial contamination. The environmental characteristics of these homes are presented briefly in Table 1. The sampled materials were affected by floodwater; however, they were dry and covered with sediment and dust at the time of collection. Although each sample collected had similar environmental characteristics to the naked eye, we did not assume an equal load of contaminating fungi. Therefore, in this study, we used the average level of aerosolized biocontaminants from the contaminated test samples. The materials were collected in clean airtight plastic bags after removal from the home using appropriate biosafety precautions. Immediately after the samples were collected from the homes, they were sent to the laboratory and stored at 25–26 °C and 59–64% RH to avoid condensation on the material surfaces of the samples, which can affect the natural aerosolization potential of biocontaminants. All samples were tested as soon as possible (<

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