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Technical note

Concentration of environmental fungal and bacterial bioaerosols during the monsoon season

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Abstract

Rain has been known to remove aerosol particles in air environments. The aerosol particles were captured and removed from the air by rain and the concentration of aerosol particles significantly decreased after rain events. Therefore, rain is regarded as having a good effect on air environments in terms of the respiratory health of the general public. However, humid environments produced by long-term rain events such as a monsoon may be a sufficient condition for the growth of microorganisms and vibrations because of the splashing of droplets may facilitate the aerosolization of ground microorganisms. We therefore hypothesize that the rain may increase concentrations of bioaerosols in outdoor air environments, thereby possibly influencing respiratory diseases.

To verify this hypothesis, at the initial stepwise approach, we measured the concentration of airborne biological particles before, after, and during rain in a monsoon season. The measurement data of the concentration of fungal particles and bacterial particles show quantitatively that the bioaerosol concentrations during the rain event are several times higher than the concentration of the bioaerosols in the condition of no rain.

1. Introduction

An aerosol is defined in its simplest form as a collection of solid or liquid particles suspended in air. Aerosols are two-phase systems, consisting of the particles and the gas in which they are suspended. These aerosol particles suspended in the air that we breathe cause health problems (Hinds, 1999). A bioaerosol is an aerosol of biological origin. Bioaerosols include viruses, bacteria, fungi, and products of organisms (fungal spores and pollen) (Lee, 2011). The sources of bioaerosols are plants, animals (including humans), soil, and water. Bioaerosols are found in many types of indoors and outdoors. They vary greatly in the way they affect, not only our health and quality of life, but also visibility and the climate (Douwes et al., 2003; Hinds, 1999).

Bioaerosols have considerable influence on public health and may play an important role in the indoor air environment. Bioaerosols are suspected to be etiological agents for respiratory diseases such as allergic rhinitis, asthma (Bush & Portnoy, 2001; Cockcroft et al., 1977; Fiegel et al., 2006; Fung & Hughson, 2010; Zuskin et al., 1994), chronic obstructive pulmonary disease (COPD) (Lacey & Crook, 1988; Matheson et al., 2005; Olenchock et al., 1990), and for infectious diseases such as influenza and Severe Acute Respiratory Syndrome (SARS) (World Health Organization: WHO, 2009). In particular, bacterial
bioaerosols are known to relate to pneumonia, tuberculosis, brucellosis, anthrax, and Q fever (Arancibia et al., 2002; LaForce, 1986). Allergic effects of bioaerosols come from chemical components of bioaerosols and infection effects of bioaerosols come from viability of bioaerosols (Robbins et al., 2000; Shelton et al., 2002). Bioaerosols also received special attention in 2001 during events of bioterrorism (Center for Disease Control and Prevention, 2001). Therefore, because of the importance of bioaerosol researches, in several previous studies, the concentration of bioaerosols has been measured in indoor environments. In those studies, bioaerosols have been measured in restrooms (Lee et al., 2012), hospitals (Li & Hou, 2003; Pastuszka et al., 2005), houses (Jeon et al., 2010; Jo & Seo, 2005; Lee & Jo, 2006; Ren et al., 1999; Roberts et al., 2006), and work places (Chang et al., 2001; Kalogerakis et al., 2005; Kim et al., 2007; Lacey & Crook, 1988; Law et al., 2001). Most previous studies show a wide range of the number concentrations of total culturable bioaerosols in indoor air environments and the results of those studies indicate the necessity of continuous monitoring and studying the indoor bioaerosol concentrations.

In addition, bioaerosols affect atmospheric chemistry (Pöhikker et al., 2012). Recently, increasing attention has been paid to the relationship between bioaerosols and the atmosphere. It is well known that the atmosphere is a conveyor of bioaerosols. However, it is also a site where significant microbial processes can take place during transport (Sattler et al., 2001). Bioaerosol particles in the atmosphere have been known to impact on the formation of clouds. Bioaerosol particles can act as ice or cloud nuclei in clouds (Huffman et al., 2013; Möhler et al., 2007; Pratt et al., 2009). Despite the importance of outdoor bioaerosol concentrations from the perspective of public health and atmospheric sciences, the current practical measurements of the concentration of bioaerosols are rare and it remains insufficient (Menetrez et al., 2007; Yeo & Kim, 2002). In particular, quantitatively measured data for special events are scarce.

In this study, we measured the number concentrations of total culturable bioaerosols in outdoor air environments rather than in indoor air environments. We focus on the effect of rain on bioaerosols among many specific events. Rain has been widely known to remove aerosol particles in air environments. The aerosol particles were captured and removed from the air by a rain event and the concentration of aerosol particles significantly decreased after rain events. Therefore, rain is considered to have a favorable effect on air environments in terms of the respiratory health of the public. However, rain events such as a long term monsoon, cause an increase in the humidity of the air environments. The humidity increase can affect the growth of the bioaerosols (Jones & Harrison, 2004). Therefore, a bioaerosol living environment may be created during this season. Furthermore, rain that may trigger bioaerosol emissions due to droplet splash vibrations can increase bioaerosol concentrations by the convective lifting of bioaerosols into the ambient air. To verify this hypothesis of the increase of bioaerosol concentrations in a monsoon season, the change in the concentrations of bioaerosols caused by rain events was evaluated in this study as an initial step for studying effects of rain on bioaerosols. We collected data before, during, and after rain events in a monsoon season in Seoul, Republic of Korea, where tens of millions people live currently. We measured the number of concentrations of total culturable fungal and bacterial bioaerosols in three outdoor air environments – in the forest, by the lake, and near a building – via a standard measurement method provided by the Ministry of Environment of the Republic of Korea. An indoor air environment – inside the lecture building of Konkuk University – was also chosen for measurements to compare with the data from the outdoor air.

The aim of this study is to provide an initial baseline understanding of the relationship between rain and bioaerosols in outdoor environments and to examine the quantitative level of concentrations of bioaerosols during rain events. This study presents the experimental results and discusses the findings.

2. Experimental methods

We used a sampler (Bio-culture sampler, Buck bio-culture, Model B30120, A.P. Buck, Inc., Orlando, Florida, US) for capturing fungal and bacterial bioaerosols. This sampler is an impactor type sampler with a flow rate of 100 l/min. The air containing fungal and bacterial particles was accelerated through 400 nozzles of the sampler and the potential fungal and bacterial particles were deposited onto the agar plate of the sampler. The potential fungal particles were deposited onto the agar which contained MEA (maltose 12.75%, dextrin 2.75%, glycerol 2.35% peptone 0.75% and agar 15%). The deposited fungal particles and normal particles were incubated at 25 °C for 48 h. The potential bacterial particles were deposited onto the agar which contained nutrient agar (beef extract 3%, peptone 5%, and agar 15%). The deposited bacterial particles and normal particles were incubated at 37 °C for 24 h. We enumerated the number of colonies and calculated the concentration of culturable fungal and bacterial bioaerosols in the air environment with the unit of CFU/m³.

Figure 1 shows the locations where measurements were conducted. The measurement campaigns were conducted at Konkuk University which was located in the west side of Seoul, Republic of Korea. The measurement area around Konkuk University was a highly crowded area in Seoul (hundreds of thousands of pedestrians every day). We measured the number of concentrations of total culturable fungal and bacterial bioaerosols in three outdoor air environments – in a forest, by a lake, and near a building – and one indoor environment. One indoor measuring location was inside a six-story building that was not air-conditioned. We sampled bioaerosols at 40 cm above the ground surface with at least three replications.

We measured the outdoor fungal and bacterial bioaerosol concentrations for the summer season in Seoul, Republic of Korea. Especially, we measured the concentrations from July 1, 2013 to July 26, 2013, which was in the middle of the monsoon season of Korean peninsula. We chose this season because we wanted to compare fungal and bacterial bioaerosol concentrations on rainy days with the concentration on days without rain. We sampled bioaerosols during lunch time (around 12:30) when many people usually go outside for taking a walk.
3. Result

3.1. Concentration of bioaerosols outside the building during rain (Building Out)

Table 1 shows concentrations of fungal and bacterial bioaerosols at three outdoor locations and at one indoor location during rain and without rain.

In our measurement campaigns, the concentrations of total culturable fungal bioaerosols were generally higher than the concentrations of total culturable bacterial bioaerosols. In every case, concentrations of bacterial bioaerosols were lower than the legal standard for public health set by the Ministry of Environment of the Republic of Korea (800 CFU/m³). There is no legal standard for fungal bioaerosols in Korea, and to the authors’ knowledge, there are no legal standards for bacterial and fungal bioaerosols in Europe, the US and Asia.

Table 1 and Fig. 2 show concentrations of fungal bioaerosols outside the building (Building Out). Surprisingly, concentrations of fungal bioaerosols during rain were much higher than those without rain. The concentrations of fungal bioaerosols during rain were approximately seven times higher than those without rain, on average. This trend was also observed for concentrations of bacterial bioaerosols. As shown in Table 1 and Fig. 3, concentrations of bacterial bioaerosols during rain were approximately twice those without rain. These results indicate that concentrations of fungal and bacterial bioaerosols outside the building increased during rain events.

In Figs. 2 and 3, concentrations of bioaerosols and PM10 (a particulate matter with a diameter less than 10 μm) showed a different pattern. Concentrations of bioaerosols increased during rain, but those of PM10 decreased. As mentioned earlier, rain has a cleaning effect. That is, rain gathers particles in the air as it falls to the ground and collects particles, including PM10. As shown in Figs. 2 and 3, the concentration of PM10 decreased during rain events, as expected. In the same air, however, the concentration of bioaerosols did not decrease, but increased during rain events.

3.2. Concentrations of bioaerosols in other locations on RD (Forest, Lake, Building (In))

In other locations (Forest, Lake, Building (In)), Table 1 and Fig. 4 show that the concentration of the fungal and bacterial bioaerosols during the rain event were much higher than those without rain. In the forest, the concentrations of fungal bioaerosols during rain were about three times higher than those without rain. The bacterial bioaerosols concentrations during rain were double of the concentration without rain. In the lake, the concentrations of fungal bioaerosols during rain were approximately six times higher than those without rain. The concentrations of bacterial bioaerosols during rain were two times higher than those without rain. In the building (in), the concentrations of fungal bioaerosols during rain were approximately seven times higher than those without rain. The concentrations of bacterial bioaerosols during rain were three times higher than those without rain. From these data, this trend of increased concentrations of bioaerosols occurred in all locations of our measurement campaigns. The results indicate that concentrations of fungal and bacterial bioaerosols increased during rain events.

4. Discussion

It is well known that concentrations of most airborne particles, including PM10, decrease during rain. However, the question of whether concentrations of bioaerosols also decrease during rain was addressed, and therefore a hypothesis was proposed. The current experimental results clearly indicate that concentrations of bioaerosols increased during rain events. At this point, these results can be explained in several ways as follows.

First, bioaerosols drop from clouds during rain events. It is known that bioaerosols serve as ice or cloud condensation nuclei (Huffman et al., 2013; Möhler et al., 2007; Pratt et al., 2009), therefore rain drops can form around fungal and
Table 1
Concentrations of bioaerosols (bacteria and fungi) in rain (rainy day: RD) and non-rain conditions (non-rainy day: NRD) at various measurement locations (Forest, Lake, Building (Out), and Building (In)). Data are expressed as CFU/m³ and t-test p-values are shown.

| Location       | Type    | Rain (RD)                  | Not rain (NRD)             | T-test P-value |
|----------------|---------|----------------------------|----------------------------|----------------|
| Forest         | Fungi   | 860 ± 200 CFU/m³ (25.4 ± 0.8 °C, 94.8 ± 5%) | 253 ± 121 CFU/m³ (26.7 ± 1.5 °C, 78.7 ± 9%) | 1.26E–09 < 0.05 |
|                | Bacteria| 287 ± 88 CFU/m³ (25.3 ± 0.8 °C, 94.6 ± 5%) | 125 ± 51 CFU/m³ (26.6 ± 1.5 °C, 72.1 ± 9%) | 0.006 < 0.05  |
| Lake           | Fungi   | 710 ± 194 CFU/m³ (27.0 ± 1.4 °C, 85.8 ± 6%) | 120 ± 62 CFU/m³ (29.0 ± 1.5 °C, 68.4 ± 9%) | 8.61E–12 < 0.05 |
|                | Bacteria| 128 ± 64 CFU/m³ (26.7 ± 1.2 °C, 85.7 ± 7%) | 67 ± 30 CFU/m³ (29.1 ± 1.5 °C, 66.6 ± 9%) | 0.043 < 0.05  |
| Building (Out) | Fungi   | 693 ± 319 CFU/m³ (26.6 ± 1.0 °C, 90.6 ± 7%) | 96 ± 45 CFU/m³ (28.4 ± 2.6 °C, 66.6 ± 11%) | 5.68E–07 < 0.05 |
|                | Bacteria| 181 ± 82 CFU/m³ (26.3 ± 1.2 °C, 91.3 ± 7%) | 81 ± 31 CFU/m³ (29.6 ± 2.8 °C, 65.4 ± 13%) | 0.017 < 0.05  |
| Building (In)  | Fungi   | 686 ± 270 CFU/m³ (26.0 ± 0.5 °C, 88.5 ± 9%) | 105 ± 62 CFU/m³ (28.2 ± 1.7 °C, 66.9 ± 10%) | 3.89E–09 < 0.05 |
|                | Bacteria| 194 ± 98 CFU/m³ (26.0 ± 0.7 °C, 89.1 ± 9%) | 64 ± 25 CFU/m³ (28.1 ± 1.4 °C, 69.1 ± 11%) | 0.010 < 0.05  |

Fig. 2. Average concentrations of fungal bioaerosols in the building (Out) and concentrations of PM10 on rainy days (RD) and non-rainy days (NRD). The full-bar graph indicates average concentrations of fungal bioaerosols on RDs. The empty-bar graph indicates average concentrations of fungal bioaerosols on NRDs. The dotted-graph indicates concentrations of PM10 (PM10 data from the Seoul branch of the Korea Meteorological Administration).

Fig. 3. Average concentrations of bacterial bioaerosols in the building (Out) on RDs and NRDs and concentrations of PM10. The full-bar graph indicates average concentrations of bacterial bioaerosols on RDs. The empty-bar graph indicates average concentrations of bacterial bioaerosols on NRDs. The dotted-graph shows concentrations of PM10 (PM10 data from the Seoul branch of the Korea Meteorological Administration).
bacterial particles at high altitudes. These bioaerosol particles in clouds and at high altitudes then descend to the earth’s surface during rain events (Sattler et al., 2001), increasing concentrations of bioaerosols.

Second, bioaerosols can splash up from the ground. Rain drops produce a lot of small vibrations on the ground, and these vibrations can detach and aerosolize microorganisms on the ground with the help of wind (Cox & Wathes, 1995; Lee, 2010; Pasanen et al., 1991). Therefore, because of the splashing of spores and microorganisms, concentrations of bioaerosols can increase.

Third, a decrease in effects of ultraviolet (UV) rays may affect concentrations of culturable bioaerosols. It is well known that UV irradiation affects concentrations of bioaerosols. UV irradiation is an effective sterilization method for bioaerosols (Hwang et al., 2010; Riley et al., 1976). During rain events, rain clouds in the sky can reduce the amount of UV irradiation (Calbó & González, 2005; Frederick & Snell, 1990). Here the survival rate of bioaerosols may increase because of reductions in UV irradiation during rain events.

Finally, an increase in humidity can affect concentrations of bioaerosols. Rain events increase air humidity, and this may facilitate the growth of microorganisms (Jones & Harrison, 2004). Moisture in the air has been known to alter integrity of cell walls or viral coats (Hatch & Wolochow, 1969). It was reported that humid environments could increase concentrations of bioaerosols in indoor environments (Frankel et al., 2012; Pasanen et al., 1991). In this study, the average humidity values at the three outdoor and at one indoor environments during rain events were approximately 20% higher than those without rain. Therefore, the humidity increase during rain events can cause the increase of bioaerosol concentrations in the measurement campaigns.

The question of why concentrations of bioaerosols increase during rain events, particularly during monsoon seasons, remains unanswered. In this regard, additional experiments with varying conditions are needed to check for dominant mechanisms underlying increases in concentrations of bioaerosols during rain.

There are several limitations in the current experimental results. The measurement campaigns were conducted at Seoul Metropolitan area in Korean peninsula for one monsoon season and only culturable bioaerosols were detected. Samplings in other areas with non-culturable bioaerosol detection cannot be covered in this study. In addition, the variation of sampling efficiency of the impactor type sampler for bioaerosols with various humidity conditions cannot be covered in this study.

5. Conclusion

In this study, outdoor fungal and bacterial bioaerosol concentrations during the monsoon season in Seoul, Korea, were measured. In particular, these concentrations during the middle of the monsoon season on the Korean Peninsula were
assessed. This season was selected to compare bacterial bioaerosol concentrations in rainy days (RDs) with those in non-rainy days (NRD).

Outside the building, concentrations of fungal bioaerosols during rain were much higher than those in non-rainy days. Concentrations of fungal bioaerosols during rain were approximately seven times those in non-rainy days. This pattern was also observed in concentrations of bacterial bioaerosols. These results indicate that concentrations of fungal and bacterial bioaerosols outside the building increased during rain events. These increases in concentrations of culturable fungal and bacterial bioaerosols during rain can be explained as follows: First, bioaerosols drop from clouds during rain. Second, particles of bioaerosols splash on the ground. Third, effects of the ultraviolet (UV) ray decrease. Fourth, an increase in humidity fosters environments friendly to fungi and bacteria. These experimental results for quantitative concentrations of fungal and bacterial bioaerosols are expected to be useful for analyzing and developing methods to control bioaerosols. In addition, the results for outdoor concentrations of fungal and bacterial bioaerosols are expected to provide useful guidelines for public health policies. Additional experiments with varying environmental conditions, including confined conditions, are needed to better elucidate the mechanisms underlying the phenomena observed in this study.

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