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Review article

A review on airborne microorganisms in particulate matters: Composition, characteristics and influence factors

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ABSTRACT

Airborne microorganisms (AM), vital components of particulate matters (PM), are widespread in the atmosphere. Since some AM have pathogenicity, they can lead to a wide range of diseases in human and other organisms, meanwhile, some AM act as cloud condensation nuclei and ice nuclei which let them can affect the climate. The inherent characteristics of AM play critical roles in many aspects which, in turn, can decide microbial traits. The uncertain factors bring various influences on AM, which make it difficult to elaborate effect trends as whole. Because of the potential roles of AM in environment and potent effects of factors on AM, detailed knowledge of them is of primary significance. This review highlights the issues of composition and characteristics of AM with size-distribution, species diversity, variation and so on, and summarizes the main factors which affect airborne microbial features. This general information is a knowledge base for further thorough researches of AM and relevant aspects. Besides, current knowledge gaps and new perspectives are offered to roundly understand the impacts and application of AM in nature and human health.

1. Introduction

AM are ubiquitous in the air, which mostly exist in the shape of attaching on the PM while few of individual, and they gradually become hot research objects with increasing studies on atmospheric PM (Munir, 2010). As important parts of PM, AM were the vital role in affecting human health, atmospheric chemistry, nucleation processes, and ecosystem interactions, they have biogeochemical connection with oceanic, atmospheric, and terrestrial environments (Bauer et al., 2003; Delort et al., 2010; Fröhlichnowoisky, 2016; Walser et al., 2015), so comprehending the microbial contents in the air has important scientific, health, and economic significances. Nevertheless, many traits of microbes, such as the actual identity, diversity, and abundance of different types as well as microbial temporal and spatial variability, are not well studied, therefore relevant researches about airborne microbial characteristics should be taken seriously from now. In most present researches about airborne microbial compositions and characters, the starting point is microbial integral distribution, and the emphasis is microbial constitutions and features in whole environment, but microenvironment and small environment also have high research value which less be studied. Size-segregated environments own study meaning because the most harmful effects of PM are related to the size of the particles (Kim et al., 2015). From culture-based methods to molecular biological techniques (Adhikari et al., 2004; Hospodsky et al., 2010; Katra et al., 2014; Kim et al., 2008; Lee et al., 2006), researchers generally have studied airborne microbial main compositions like bacteria, fungi, viruses and archaea with their concentration, size distribution and diversity in order to know their peculiarities. Besides, AM have variability caused by themselves and other factors. Common influence factors contain meteorological parameters, particles, source, time, location, and human and animal activities (Dallavalle, 1958; Haas et al., 2013; Peccia et al., 2001; Yadav et al., 2015), and they have different effects on AM. Over the last decade, the studies in field about influence factors exploration have increased gradually, but the concrete effect mechanisms are not clear that still need to be researched. The objective of this paper is to review knowledge about airborne microbial various characteristics and their influence factors. These aspects account for the manifold importance of the microorganisms in the atmosphere, provide preconditions of subsequent researches about impacts and solutions of AM on other sides like health risk assessment and allow insight in possible applications of these organisms.

2. Composition of AM

Microorganisms are omnipresent in the atmospheric environment, which mainly include bacteria, fungi, actinomycetes, viruses, pollen,

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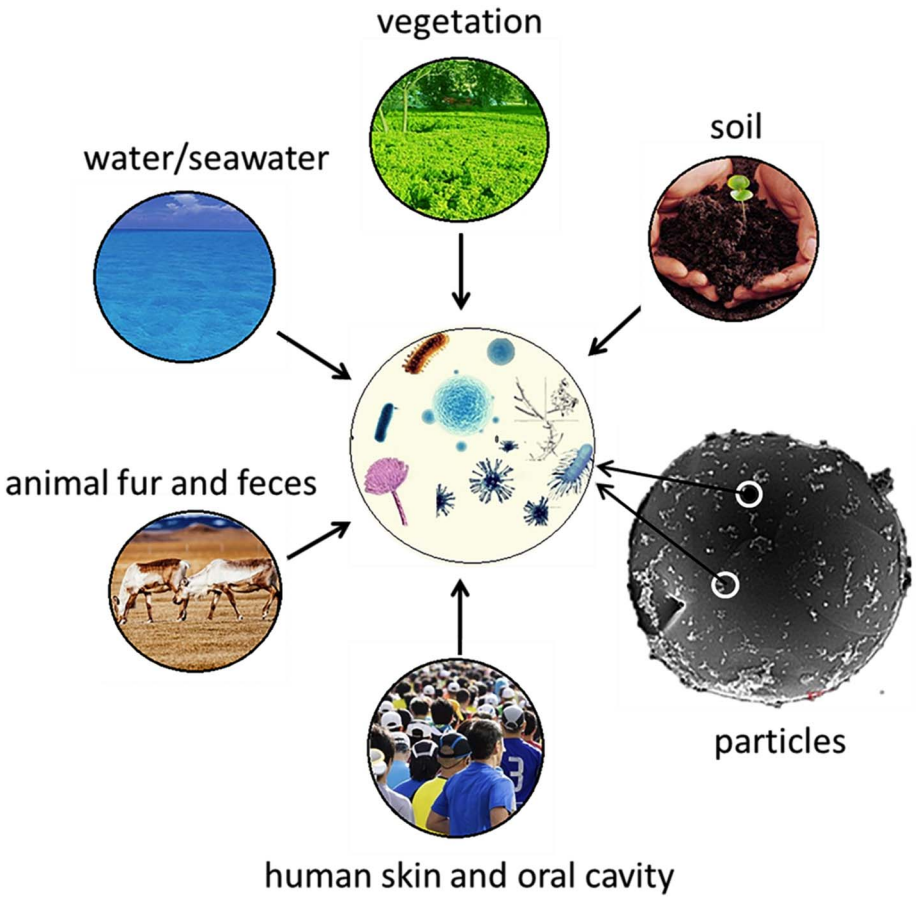

Fig. 1. Main sources of airborne microbes over particles.

and a little archaea (Stetzenbach et al., 2004). The atmosphere is considered as one of habitats for AM originated from soil, water/seawater, vegetation and else places (Fig. 1). Though atmosphere owns some hard conditions such as high solar radiation, low moisture and nutrients and large dispersing capability, it gradually evolved into one of the habitats for microbes, there are still a large amount of microbes in the air now (Henderson and Salem, 2016). According to estimation, nature has about 40 thousand bacteria, 1.5 million fungi and 130 thousand virus, but actually the species, found and detected by current research methods, are little (Hawksworth, 2001). Under various settings, microbial compositions are distinguishing (Fig. 2), but the trends of scale in microbes are the similar that generally detected bacteria are the most about 80%, next are fungi, finally are others. These microbes can exist in the air mostly depend on PM which are primary carriers for AM, and the pattern AM existing on PM is adhesion, a way for AM to establish community and sustain life in a particular habitat. Meanwhile, PM can offer AM nutrients to prevent starving conditions and maintain AM's metabolism with likely high nutrients on surface of PM when air settings around PM haven't enough nutrients, and PM also can provide the occupants with a shield as decreasing harm by ultraviolet radiation (Kharangate-Lad, 2015; Maier and Gentry, 2015). Compared with AM on PM, the AM that exist as individuals may be more likely to die. AM attaching to particles gradually form many abundant and mutable communities as numerous microbial species and different shares of each microbial constituent, which generate microbial diversity over PM (Lighthart, 2000). The diversity and interaction among these microbes will have an effect on themselves and external environment. Airborne microbial composition can provide rich information about themselves, like their portions, properties and characters, and comprehensive knowledge can help researchers lay a foundation for subsequent studies about AM.

2.1. Bacteria

The study topics of AM are constantly increasing, which ranged from exploring their existence and metabolic activity in atmosphere to researching their potential pathogenicity and influence on climate and human health (D'Arcy et al., 2012; Polymenakou, 2012; Salonen et al., 2015; Šantl-Temkiv et al., 2015). Bacteria are common research objects with the concentration ranging between 10 and 10^7 cell per·m^3 in the air detected by methods like culture methods, bio-molecular technology and quick estimation model (Albrecht et al., 2007; Bertolini et al., 2013; Bowers et al., 2012; Lange et al., 1997; Lee et al., 2010; Li et al., 2010; Liu et al., 2017b). Bacteria can exert a certain extent influence on many aspects, like Gram-negative bacterial contamination relate to endotoxins that can bring adverse effects, and some bacteria have infection and toxicity may result in various microbial diseases of human and plants when higher concentration (Liang et al., 2013; Traversi et al., 2011), and some may impact cloud development and atmospheric chemistry (Andreae and Rosenfeld, 2008; Burrows et al., 2009). Hence, bacterial characteristics are vital for AM studies to broaden the knowledge and deepen the cognition.

2.1.1. Size distribution

Different bacteria have respective sizes ranging from 0.1–5 μm, and each bacterium has particular shape feature that plays an important role in the adhesion on PM (DeLeon-Rodriguez et al., 2013; Grinshpun et al., 1995). With smaller size, bacteria are easier to attach to fine particles like $PM_{2.5}$ even smaller particles. Generally, particle size is an essential factor that determines PM's inhalable degree which have a crucial effect on human health, so bacterial size distribution is a significant content of researching health risk assessment exposure to airborne bacteria for human (Kawanaka et al., 2009). Hot research topics are more put on small particles including 'inhalable coarse particles'