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Review

Microbial interactions: ecology in a molecular perspective

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ABSTRACT

The microorganism–microorganism or microorganism–host interactions are the key strategy to colonize and establish in a variety of different environments. These interactions involve all ecological aspects, including physiochemical changes, metabolite exchange, metabolite conversion, signaling, chemotaxis and genetic exchange resulting in genotype selection. In addition, the establishment in the environment depends on the species diversity, since high functional redundancy in the microbial community increases the competitive ability of the community, decreasing the possibility of an invader to establish in this environment. Therefore, these associations are the result of a co-evolution process that leads to the adaptation and specialization, allowing the occupation of different niches, by reducing biotic and abiotic stress or exchanging growth factors and signaling. Microbial interactions occur by the transference of molecular and genetic information, and many mechanisms can be involved in this exchange, such as secondary metabolites, siderophores, quorum sensing system, biofilm formation, and cellular transduction signaling, among others. The ultimate unit of interaction is the gene expression of each organism in response to an environmental (biotic or abiotic) stimulus, which is responsible for the production of molecules involved in these interactions. Therefore, in the present review, we focused on some molecular mechanisms involved in the microbial interaction, not only in microbial–host interaction, which has been exploited by other reviews, but also in the molecular strategy used by different microorganisms in the environment that can modulate the establishment and structuration of the microbial community.

Introduction

Microbial interactions are crucial for a successful establishment and maintenance of a microbial population. These interactions occur by the environmental recognition followed by transference of molecular and genetic information that include many mechanisms and classes of molecules. These mechanisms allow microorganisms to establish in a community, which depending on the multi-trophic interaction could

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result in high diversity. The result of this multiple interaction is frequently related to pathogenic or beneficial effect to a host. In humans, for example, the microbial community plays an important role in protection against diseases, caused by microbial pathogens or physiological disturbances. Soils microbial communities also play a major role in protecting plants from diseases and abiotic stresses[1] or increasing nutrient uptake.

Microorganisms are rarely encountered as single species populations in the environment, since studies in different habitats has shown that an enormous richness and abundance variation are usually detected in a small sample, suggesting that microbial interactions are inherent to the establishment of populations in the environment, which includes soil, sediment, animal, and plants, including also fungi and protozoa cells. The many years of coevolution of the different species lead to adaptation and specialization and resulted in a large variety of relationships that can facilitate cohabitation, such as mutualistic and endosymbiotic relationships, or competitive, antagonistic, pathogenic, and parasitic relationships.[2]

Many secondary metabolites have been reported to be involved in the microbial interactions. These compounds are usually bioactive and can perform important functions in ecological interactions. A widely studied mechanism of microbial interaction is quorum sensing, which consists in a stimuli-response system related to cellular concentration. The production of signaling molecules (auto-inducers) allows cells to communicate and respond to the environment in a coordinated way.[3] During interaction with the host cells, microbial-associated molecular patterns (PAMP or MAMP – microbial-associated molecular pattern) are conserved throughout different microbial taxon allowing to increase the fitness during interaction with plant or animal cells[4] and regulating the microbial interactions with different hosts (Table 1).

Much attention has been given to researches on microbial interactions in the human health field. The microbial interactions are crucial for the successful establishment and maintenance of colonization and infection. Additionally, antimicrobial host defenses and environmental factors also play essential roles. Microorganism communication enables the population to collectively regulate the gene expression in response to host and environmental signals, produced by the same or even by different species. This results in a coordinate response in the microbial population, achieving successful pathogenic outcomes that would not be accomplished by individual cells.[5–7]

Consequently, knowledge on the mechanisms involved in the microbial interactions can be a key to developing specific agents that can avoid or disturb microorganism communication during infection and consequently act to decrease the defensive and offensive qualities of the pathogen. Thus, the study of these mechanisms can contribute to the understanding of the microbial pathogenesis and to the development of new antimicrobial drugs.[5,8]

In addition, microbial interactions occurring in human host can also be benefic and some diseases are often related to imbalances in the healthy microbiota. Therefore, studies on the healthy microbial community in the host are also relevant as it can lead to disease prediction and its appropriate therapies.[9–11]

Microbial interactions also deserve attention from the natural products discovery field. Secondary metabolite clusters that are silent under laboratory growing conditions, can be activated by simulating the natural habitat of the microorganism. It has been reported that co-cultivation with others microorganisms from the same ecosystem can induce the activation of otherwise silent biosynthetic pathways leading to the production and identification of new natural products.[12–16] Furthermore, this knowledge can also be applied to genetic engineering of phytopathogens antagonists/parasites aiming to an enhanced biological control.[17]

In this review, we focused on the molecular mechanisms involved in many microbial interactions, involving intra and interspecies microbial interactions and the microorganism interaction with the host.

Organisms involved

Microorganisms rarely occur as single species populations and are encountered in many hosts/environments, thus there is a large variety of types of microbial interactions concerning the organisms involved. Bacteria–bacteria, fungus–fungus, bacteria–fungus, fungus–plant/animal, bacteria–plant/animal and bacteria–fungus–plant/animal interactions, including parasitic, mutualistic interactions involve many mechanisms that have been described, allowing to develop strategies to manipulate these interactions, which could result in increased host fitness or new metabolite production. According to van Elsas et al.,[18] the establishment of a new species (invader) in an environment depends on the characteristic of the local microbial community. In general, ecosystems that lost species diversity present less ability to resist to an invader, since present more available niche that could be occupied by indigenous species. In addition, during the niche occupation, the invader should interact with species present in this environment.

The mechanisms involved in archaeal interactions are largely unknown, although they are very important in the archaeal communities, production of methane in landfills,[19] archaea in soil and rhizosphere ecosystems,[20] thermophilic archaea in bioleaching process,[21] for example. Virus interactions with its host are also very important since viruses are responsible for many diseases in a variety of hosts, and also, modulating the bacterial community by infecting dominant species. Host-virus communication is related to RNA-based mechanisms such as microRNAs.[22,23] The microorganisms addressed in the present reviewed comprise fungi and bacteria, we did not focus on virus or archaeal.

Fungi and bacteria interactions are widely studied, although the molecular mechanisms involved in the interactions are often not completely understood. They interact with a wide range of different organisms – plants, humans and other animals, among others – in different environments, as we describe in this present review, and present many biotechnological applications, such as in food processing, bioremediation, medicine, and biocontrol. In

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