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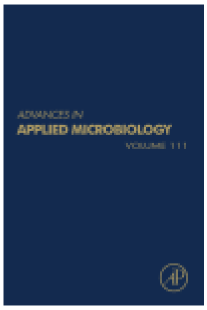

Chapter Four - Advances in the control of phytopathogenic fungi that infect crops through their root system

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Abstract

Productivity and economic sustainability of many herbaceous and woody crops are seriously threatened by numerous phytopathogenic fungi. While symptoms associated with phytopathogenic fungal infections of aerial parts (leaves, stems and fruits) are easily observable and therefore recognizable, allowing rapid or preventive action to control this type of infection, the effects produced by soil-borne fungi that infect plants through their root system are more difficult to detect. The fact that these fungi initiate infection and damage underground implies that the first symptoms are not as easily

noticeable, and therefore both crop yield and plant survival are frequently severely compromised by the time the infection is found.

In this paper we will review and discuss recent insights into plant-microbiota interactions in the root system crucial to understanding the beginning of the infectious process. We will also review different methods for diminishing and controlling the infection rate by phytopathogenic fungi penetrating through the root system including both the traditional use of biocontrol agents such as antifungal compounds as well as some new strategies that could be used because of their effective application, such as nanoparticles, virus-based nanopesticides, or inoculation of plant material with selected endophytes. We will also review the possibility of modeling and influencing the composition of the microbial population in the rhizosphere environment as a strategy for nudging the plant-microbiome interactions toward enhanced beneficial outcomes for the plant, such as controlling the infectious process.

Introduction

Molecular evidence indicates that fungi evolved over a billion years ago (Parfrey, Lahr, Knoll, & Katz, 2011), whereas their first interactions with plants are estimated to be as old as 425 million years, the moment when plants began to colonize terrestrial ecosystems (Redecker, Kodner, & Graham, 2000). Since then, through an intricate process of co-evolution, countless interactions have taken place between plants and fungi. The result is a remarkable capacity of many fungi to associate with and colonize not only the root system, but also the aerial parts of plants. Fungus-plant interactions at the root level can be beneficial for both members of the association, establishing a permanent and intimate mutualistic symbiosis called mycorrhiza (Strack, Fester, Hause, Schlieman, & Walter, 2003). Although there are different types of mycorrhizas (ectomycorrhizas and endomycorrhizas), endophytic arbuscular mycorrhizas (AMs) that develop between fungal species of Zygomycota and roots of most terrestrial plants (more than 90% of plants are estimated to be colonized by AMs) are the most important. AMs have both a great ecological and economic impact and are responsible for nutrient exchange between the host and the symbiont, uptake and adsorption of mineral nutrients (especially phosphate), transport of carbohydrates from the plant to the fungus, and water from the fungus to the plant (Strack et al., 2003). Mycorrhizae formation is, therefore, a consequence of the ability of certain fungi to infect and colonize the plant cortex. Unfortunately, many other fungi have evolved to infect plants and use them as a food source. Currently, according the manner in which fungi infect and colonize plant tissues, up to three different types of fungi can be distinguished (Pawlowsky & Hartman, 2016). Biotrophic fungi are highly specialized and require living cells as their nutrient source. In fact, many of them are obligate biotrophs, completely dependent on their host plant to develop and survive. Biotrophic fungi can produce a variety of diseases like hyperplasia or hypertrophy (galls and deformations) due to intensive cellular proliferation of the affected organs: pustules formed by breaches in epidermis, smuts or areas of affected tissue looking dark and charred; and bloom of spore-bearing parasites on the surface of affected organs, the most common being powdery and downy mildews (Dyakov & Zinovyva, 2007). Necrotrophic fungi, or necrotrophs, have evolved different mechanisms for killing plant cells prior to infection and colonization, later feeding on the dead tissues. Necrotrophs can cause a wide variety of major disease types including root rots, trunk rots and trunk diseases, post-harvest rots, tracheomycosis, which affects xylem vessels, and canker lesions of tree bark (Dyakov & Zinovyva, 2007). Finally, some fungi exhibit biotrophic and necrotrophic phases and are thus called hemibiotrophs. They initially require living plant tissues to develop. As their life cycle progresses, they kill their host cells, subsequently feeding off the dead tissue. They are responsible for many leaf damage and spot diseases (Dyakov & Zinovyva, 2007).

Phytopathogenic fungi can infect and colonize any part of the plant. Many of them develop on external, aerial parts of the plant in such a way that their symptoms are easily noticeable, allowing their rapid detection. However, many other phytopathogenic fungi have specialized as soil-borne phytopathogens and are able to complete their life cycles in the soil. The root system is the preferred entry point for these fungi and they are especially dangerous since they initiate the infection and do their damage underground, and thus the first symptoms are not easily detectable. When they appear on the aerial part of the plant, both crop yield and plant survival are already severely compromised.

In this chapter we will review the different methods and technologies that can be applied to fight and control soil-borne phytopathogenic fungi that infect the host plant through the root system.

Section snippets

Soil-borne phytopathogenic fungi infecting plants through their root system

Soil-borne phytopathogenic fungi are one of the most challenging problems that agriculture must face. There are several factors that make this type of pathogen extremely dangerous. First, many fungal species belonging to Basidiomycota and Ascomycota phyla behave as soil-borne pathogens. Secondly, although most of them are necrotrophs or hemibiotrophs feeding off dead plant tissues, they can also proliferate and survive (even under adverse conditions) for long periods of time on plant residues

Control of fungal infections through the root system

Many soil-borne phytopathogenic fungi able to thrive in soils can infect their hosts by penetrating their root system. As indicated before, this is a worrisome aspect since the first symptoms of infection only appear when the health of the plant is already severely compromised. Therefore, control of these pathogens is a challenging issue due to their ability to survive in soils and current limitations in the use of synthetic pesticides, among other factors. Accordingly, in the last decades

Strategies for the application and/or introduction of biocontrol agents, or antifungal compounds, into the root system

While considerable effort has been made to search for biocontrol agents or natural compounds to inhibit soil-borne pathogens, a great problem arises when it comes to making them effectively reach the place of action of these pathogens, the root system, or the xylem itself, that the pathogens use to enter the plant. In fact, although the scientific works dealing with biocontrol of soil-borne pathogens are countless, the use of registered BCAs is limited, mostly because of the lack of efficacy

Modeling the rhizosphere microbiome for controlling fungal infections

The rhizosphere is that narrow zone of soil that is in direct, intimate contact with the root and is influenced by root activity. The rhizosphere can contain up to 10^{11} microbial cells per gram, thereby supporting largely increased bacterial and fungal abundance and activity, as compared to bulk soil (Egamberdieva et al., 2008). Microbial diversity of the rhizosphere is also very high, and in fact, there are estimations quantifying the prokaryotic diversity in more than 33,000 species per gram (

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