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## Future Trends in Biocontrol

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### I. INTRODUCTION

Historically, research in biocontrol has yielded discoveries of both fundamental biology and solutions for practical problems in agriculture. Advances on both fronts will be furthered by a better understanding of the complex ecology that surrounds the disease-retardant interactions of microorganisms and plants. The emerging tools of modern biology afford increasingly sophisticated approaches to dissect the multichannel dialogue among the plants, pathogens, biological control agents, and microbial communities that provide the biological context for disease and its suppression. As these research avenues are pursued, new principles of organismal interactions and community function and new strategies for deployment of biocontrol agents will emerge.

To realize the practical potential of biocontrol for agricultural production, it will be imperative to unite knowledge of mechanistic interactions with an appreciation of the complexity of the agroecosystem. Understanding the recognition, signaling, and cooperative and antagonistic interplay between the biological partners will lead to strategies to direct the outcome of the interaction more precisely and consistently. Knowledge of the events leading to disease control may suggest modifications in the timing, placement, and formulation of the biocontrol agent to achieve maximum disease control. Similarly, that knowledge may indicate situations in which certain biocontrol agents will not be successful and may thus lead to wiser choices to tailor the agent to the physical, chemical, and biological context into which it will be introduced.

The future research challenges in biocontrol move beyond the suppression of plant disease to include impacts on human health and registration processes.

Research will be needed to address the safety of biocontrol agents, as well as their efficacy, to avoid public health disasters, allay concerns of the general public, satisfy regulatory agencies, and promote commercial acceptance.

## **II. FUNDAMENTAL BIOLOGY**

Research on biocontrol has been an important vehicle for expanding our knowledge of environmental microbiology. Through biocontrol research, new antibiotics have been identified, the basis for mycoparasitism has been elucidated, and mechanisms of nutrient competition among microbes have been empirically substantiated. Future research in biocontrol is likely to contribute to our knowledge of fundamental biology in microbial community function. Specifically, the structure of microbial communities, signaling among members of the community and from the community to plants that serve as hosts for them, and the basis for mutual dependence among members of microbial consortia will be key areas for study.

In the field, biocontrol agents must be effective in a complex biological milieu. The leaves, flowers, seeds, and roots on which biocontrol agents must suppress the action of pathogens are teeming with other microorganisms. The communities on these surfaces are in flux, influenced by cycles of moisture, temperature, light, and jetties of air or water. Thus, the biocontrol agent must contend with a complex physical environment that is constantly changing the biological environment that provides both assistance and competition to the biocontrol agent.

Despite the importance of microbial communities on plant surfaces, much biocontrol research has ignored their influence by studying biocontrol in laboratory settings with much simpler microbial communities than occur in the field. While this choice has led to the precise dissection of mechanisms of biocontrol that could not have been delineated so clearly in a more complex environment, the cleanliness of the lab setting is certainly not a reasonable approximation of the field environment. It is no surprise, therefore, that many biocontrol experiments have produced divergent results in the lab and field. The microbial communities on plant surfaces may be a key to understanding the discrepancies between lab and field results. If we are to understand the network of events that cooperate to effect disease suppression, then we must begin to understand the community context in which the key events occur. This context is difficult to study, and improved methods are needed. Thus, the future of biocontrol research must include experimental strategies to understand the interaction of the biocontrol agent and the community into which it is introduced and in which it is expected to function.

## **A. Community Dynamics**

The first step in understanding community function is to describe the membership of the community. Some studies have provided an inventory of rhizosphere or phyllosphere communities in the presence and absence of a biocontrol agent. However, no study to date has followed community dynamics over the time scale that is relevant to a microorganism—minutes or hours. Such detailed studies are largely beyond today's technology for tracking either cultured organisms or molecular markers for uncultured communities. However, it may be the community fluctuations that occur over short intervals that determine the outcome of biocontrol applications. Consequently, it is imperative that the next phase of innovation in microbial detection includes developing the capacity to monitor community dynamics on a bacterial time scale.

## **B. Community Signaling**

A second key area for future study is signaling among members of the microbial community and between the community and the plant host. The last decade has cracked open the fascinating arsenal of molecules that constitutes the language of microbes. Studies of biocontrol agents revealed that microbes use a variety of molecules to carry on functions as diverse as inciting defense responses in plants and sensing their own population densities. Perhaps one of the notable surprises that provides a directional signal for future research is that quorum-sensing molecules can be shared among members of different species. Communication among microbes within a community with small molecule signals could be the unifying element that makes the community an entity that enables the members of the community to know their place and their jobs. A substantial research effort in chemical communication in communities is likely to reveal that a cornucopia of chemical messages play a role in biocontrol by enabling the biocontrol agent to sense its surrounding, change the behavior of its competitors or cooperators, or alter the plant's defenses (see Chapter 16) or its contribution of carbon or other nutrients to the nutritional base available to the community.

## **C. Microbial Consortia**

Biocontrol usually involves the isolation, culturing, and application of a single microorganism. And yet, most organisms live in close association with other species that provide services for them, including nutrient production and waste removal. It may, therefore, be unrealistic to expect many organisms to perform optimally in terms of growth, spread, and antagonism against a pathogen without providing the members of the community on which they depend. Biculture or

dual culture (see Chapter 17) has often been thought to be successful because of the combined effects of the biocontrol agents on the pathogen, but it is also possible that the two microorganisms provide direct benefit to each other. An understanding of community functions in terms of interdependence of microorganisms may provide insight into all microbial communities and may suggest mixed inocula for biocontrol that will be more effective than single cultures.

### **III. APPLICATIONS**

The yield of commercial products spawned by the modest amount of biocontrol research supported by public and private agencies is impressive compared to the number of fungicides that have resulted from the massive, multibillion dollar investment in fungicide research led largely by the agrichemical companies. The reputation of biocontrol, however, is that few agents work reliably or as well as their synthetic chemical counterparts. It is likely that the frequency of failure of biological versus chemical experimental agents is no different. The difference may be that chemical agents have been tested largely by private companies and many of their results have remained confidential; their reports to the scientific community mostly deal with the successful chemicals that become products. In contrast, biological agents have been tested mostly by public sector scientists who publish or discuss with colleagues the results of both successful and unsuccessful trials. A record of success and safety is the only means to reverse the reputation of biocontrol, and to achieve this record the practical issues discussed here must be addressed.

#### **A. Formulation Challenges**

Even among those biocontrol agents that have successfully made the difficult transition from lab to field conditions, the record for transfer from experimental field conditions to on-farm use has been abysmal. Many agents that perform spectacularly, in some cases as well as the best synthetic pesticide, under controlled conditions demonstrate little or no efficacy under agricultural production conditions. A significant barrier appears to be survival of the biocontrol agents when they are fermented, formulated, and applied in scale. Under experimental conditions, it is feasible to prepare the inoculum within 24–48 hours of planting, whereas under production conditions the inoculum often must survive transportation on seed or in packages. An area of future research that will have important implications is the formulation of biocontrol agents to facilitate storage and transport to the site of use. Gains have been made in this area by providing stabilizing and nutritional agents for fungi and bacteria in the formulations (see Chapters 17 and 18) as well as in the use of species that produce hearty resting structures

such as spores, but more progress in this area is needed to expand the acreage and types of crops in which biocontrol can be used reliably.

## **B. Safety**

Biocontrol has long been touted as a safe alternative to synthetic pesticides. Recent developments in human health challenge this assertion. The elevation of importance of opportunistic human pathogens in recent years has led to public concern about the widespread use of certain bacteria and fungi in agriculture. The emergence of immune-compromising infectious diseases and the increase in organ transplants, which are accompanied by temporary or long-term immune suppression to prevent tissue rejection, have made opportunistic pathogens a more visible threat to human health. Many biocontrol agents are—or are closely related to—opportunistic pathogens. Examples of biocontrol organisms of questionable safety abound. *Pseudomonas aeruginosa*, a biocontrol agent of gray leaf spot on turf (see Chapter 14) is a virulent opportunistic pathogen infecting surgical wounds and severe burns. *Burkholderia cepacia*, a highly successful biocontrol agent of pea root rot and other diseases, is associated with opportunistic lung infections of patients with cystic fibrosis. *Trichoderma viride* is an opportunistic human pathogen and is on the biological warfare list in some countries (see Chapter 17). *Bacillus cereus*, a biocontrol agent of soybean damping-off and root rot, is a known food toxicant and is closely related to *B. anthracis*, the causal agent of anthrax and a focus of biological warfare threats. The microbiological question that emerges in each of these cases is whether the strains used for biocontrol are in fact pathogenic to humans or whether they simply fall in the same species as a known pathogen. Given the variation of strains within a species and the state of confusion in microbial taxonomy today, this question is not easy to answer. The epidemiological questions that require attention center around the significance of agricultural use of these organisms in exposure of immunocompromised people to these agents. Some of the bacteria are so abundant in the environment that it is possible that exposure to natural populations, which cannot be controlled, far exceeds the exposure likely to result from agricultural applications except to people working in production facilities or on farms that use these products.

The human safety issue may present some of the most important unaddressed questions in biocontrol research. If left unanswered, the concerns may block public acceptance, registration, and adoption of biocontrol agents. If a serious threat exists, even with one of the many biocontrol agents on or near the marketplace, ignoring these risks could lead to highly visible human infections associated with the use of biocontrol agents. The results of such a disaster would be personal tragedy as well as indelible damage to the reputation of all biocontrol agents. It is in the interest of public safety as well as the continuance of biocontrol research for researchers in the area to take an interest in and encourage the

environmental/medical/epidemiological studies that will answer the critical safety questions.

### **C. Cost**

The challenges of formulation and safety testing generate substantial costs associated with the development of biocontrol agents for the marketplace. This presents a paradox for the industry: while biocontrol has long been lauded as more specific and targeted than synthetic pesticides, it is difficult to justify the costs of development for a narrow market, which is the natural outcome of a finely targeted agent. Therefore, the market pressures push the industry toward broad-spectrum biocontrol agents that suppress a spectrum of diseases on many large acreage crops. Certainly not all biocontrol agents on or near the market meet these criteria, but as regulations become more stringent, performance expectations higher, and safety issues more visible, the economic pressures will increase, driving the industry further in this direction. Interesting questions arise from the predicted movement of development of biocontrol agents toward common diseases of widely grown crops. If biocontrol agents are used on massive acreages, will the selection pressure for pathogens that are resistant to, or overcome the effects of, the biocontrol agent be increased, thereby shortening the effective life span of the product? Is it biologically feasible to find single organisms that are adapted to diverse locations, agroecosystems, and environmental conditions? Are there ecological events unique to large-scale application of microorganisms that might lead to concerns for environmental safety? The answers to these questions will reveal important biological principles as well as provide guidance for the development of biocontrol as a significant aspect of modern agricultural practice.

## **IV. CONCLUSION**

By most definitions, biocontrol is an applied field of research involving the human use of a microorganism to enhance crop productivity. But the research generated by the desire to use this practice in agriculture has revealed fascinating biology and led to copious fundamental discoveries. The opportunity to conduct such basic research is coupled with a responsibility to solve the practical problems that prevent the successful deployment of many biocontrol agents. Future trends in biocontrol research will unite fundamental biology with the quest for solutions that will make biocontrol integral to the safe and wise management of every agroecosystem.