BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Integrated disease management of wheat and barley

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Contents

Part 2 Key challenges in integrated disease management of cereals

Introduction

Diseases remain a serious problem in wheat and barley cultivation. It has been estimated that around 20% of global crop production is lost to diseases. Leading fungal diseases affecting wheat and barley include rusts, Septoria blotches, powdery mildew, tan spot, spot blotch, net blotch, scald and Fusarium species. Conventional control using fungicides faces a number of challenges such as increasing regulation and the spread of fungicide resistance. The chapters in this volume sum up the wealth of research addressing this challenge. The volume reviews key recent research on the main fungal diseases, their modes of infection and potential strategies for dealing with them. The volume also looks at key challenges in developing integrated approaches to disease management, from breeding more resistant varieties to improved identification of disease and the use of natural antifungal compounds.

Part 1 Fungal diseases of cereals

The first part of the volume reviews the latest research on understanding the main fungal diseases of cereals. Chapter 1 examines rusts affecting wheat and barley. The chapter explores the incidence and impact of wheat and barley rust diseases. The chapter then examines genes for rust resistance and the pathogen biology of rusts, before going on to consider integrated methods of rust control. Finally, the chapter addresses the challenge of achieving durable resistance to rusts in wheat.

Moving from rusts to another class of fungal diseases, Chapter 2 considers the biology and management of Fusarium diseases. The chapter reviews yield and quality losses caused by Fusarium. It then summarises recent findings on Fusarium-cereal interactions, mode of infection and host-plant responses. The chapter then discusses the way this understanding can be used to improve integrated disease management of Fusarium. As well as assessing what we know about understanding and improving genetic resistance, it also discusses work to identify new fungicide molecules that aim for specific fungal metabolic pathways during infection at an early stage. The chapter also discusses the effectiveness of integrated management techniques such as ways to prevent initial infection, changes to tillage and fertilization practices, the role of rotations, more targeted use of fungicides and the use of biological control agents. Finally, the chapter also reviews what we know about the mycotoxins produced by Fusarium fungi and what can be done to reduce them.

The subject of Chapter 3 is Septoria tritici blotch (STB), a fungal disease affecting wheat. STB is one of the most common and economically-important diseases of wheat worldwide. Fungicides have been the primary means of disease management since the 1980s, but resistance has rendered some compounds ineffective. Qualitative or quantitative resistance genes have now been found on all 21 wheat chromosomes, giving a rich but complex source of genes for plant improvement. Molecular markers are now available for many resistance genes making marker-assisted selection for increased resistance an achievable goal for the future. The first STB resistance gene has now been cloned but the mechanism of resistance remains a mystery. Despite the huge progress made during the past twenty years, STB remains a difficult disease that is likely to require substantial future efforts for its control. Building on the latest research on host-pathogen interactions,

the chapter evaluates current methods of disease management, particularly in improving resistance, ongoing challenges and future trends in managing the disease.

Chapter 4 moves on to consider the characteristics and effects of powdery mildew. Powdery mildew pathogens are among the most important cereal disease-causing organisms, and can result in significant losses in yield and reductions in grain quality. They pose a significant challenge for barley and wheat agricultural production systems. The chapter provides an overview of current knowledge on wheat and barley resistance to powdery mildew. The chapter discusses current research on disease biology and epidemiology and how a better understanding of the basic molecular mechanisms of cereal-mildew interactions can be used in disease management. The chapter reviews the efficacy of management techniques. These include altering seeding rates and irrigation to create a more open crop canopy structure and less disease-conducive micro-climate, splitting nitrogen applications, removing volunteer plants, more targeted use of fungicides as well as the potential the use of biopesticides. A particular focus is improving resistance. The chapter reviews new approaches for fast gene isolation in wheat and barley, the identification of resistance genes and research into the molecular mechanisms underlying resistance. The chapter includes a case study on the identification, functional characterization and applications of the Pm3 wheat powdery mildew resistance genes in wheat breeding.

The next fungal disease of wheat to be considered, in Chapter 5, is tan spot. The chapter focuses on disease management, including cultural practices, chemical control, and the impact of the choice of wheat varieties. The chapter presents a detailed case study of the management of tan spot in Brazil, and considers the importance of host-pathogen interactions and the genetics of host resistance. Finally, the chapter includes a case study of ToxA-assisted breeding for tan spot resistance in Australia.

The focus of Chapter 6 is Septoria nodorum blotch. The chapter describes the causal agent of Septoria nodorum blotch, the fungus *Parastagonospora nodorum*, and outlines methods of disease management. The chapter examines genetic factors that produce resistance to Septoria nodorum blotch, and explains the process of the genetic mapping of resistance and the use of markers in breeding. Finally, the chapter presents a detailed case study on resistance to Septoria nodorum blotch in Norwegian wheat. Moving on to a lesser-known pathogen of wheat, Chapter 7 considers the challenge posed by *Bipolaris sorokiniana*. The chapter describes the geographic distribution of the disease and describes how *Bipolaris sorokiniana* causes disease in wheat, focusing on the fungus's pathogenic variability as well as methods of disease management.

Chapter 8 considers wheat blast, describing the characteristics, origin and survival of this fungus, based on the experience of managing the disease in Brazil (where losses are particularly high). The chapter describes the disease's origin, disease symptoms and conditions for wheat blast development, and the latest research on its causal agent. Finally, the chapter considers both genetic and chemical control options for wheat blast. The subject of Chapter 9 is net blotches. The chapter addresses the available control measures for net blotch, considering host-pathogen genetic interactions in both the spot and net forms of net blotch. The chapter includes a detailed case study on the subject of breeding for durable resistance to the net form of net blotch in South Australia.

The final chapter of the section, Chapter 10, deals with scald (leaf blotch), which is caused by the hemi¬biotrophic pathogen *Rhynchosporium commune*. Scald is one of the major diseases of barley worldwide. The chapter reviews the origins, epidemiology and other characteristic features of scald, and considers the agricultural consequences of the

pathogen's biology. The chapter then considers resistance breeding programs, in which more than a dozen major resistance genes as well as quantitative trait loci (QTLs) have been identified, and discusses strategies to minimize the damage caused by the disease, including agricultural practices and combinations of different fungicides.

Part 2 Key challenges in integrated disease management of cereals

The second part of the volume discusses key challenges in integrated disease management of wheat and barley. These challenges include developing new fungicides, the problem of fungicide resistance, breeding disease-resistance varieties, improving disease identification and the use of natural antifungal compounds. The focus of Chapter 11 is the key challenges in developing new fungicides to treat cereal diseases. The chapter considers the current status of global wheat production, the impact of crop loss on food security, and the emergence of the current regulatory environment surrounding pesticides. The chapter then discusses the current status of the global fungicide market, and some of the major issues in its future longevity: the development of resistance to active ingredients, the impact of legislation that may restrict or remove active ingredients from the market, and the rising costs of developing new active ingredients.

Chapter 12 moves on to examine the occurrence of fungicide resistance in cereal diseases and ways to avoid it. The targeted use of fungicides can help minimise the yield losses caused to grain cereals by plant pathogenic fungi. However, the long-term use of fungicide classes based on a single mode of action has imposed consistent selection pressures on certain pathogens. Over time, this has resulted in many cases of fungicide resistance, leading to a reduction or the total loss of field performance of a range of active ingredients. There is a pressing need to develop better anti-resistance management strategies. The chapter briefly reviews the development of resistance in cereal pathogens, before presenting and evaluating a variety of anti-resistance strategies. The chapter includes detailed case studies of how data from field trials have helped to illustrate the effectiveness of different control strategies.

Complementing the previous chapter's focus on breeding for resistance, Chapter 13 concentrates on improving genetic resources in the breeding of disease-resistant varieties of wheat and other cereals. The chapter highlights recent advances in phenotyping, genotyping and other breeding technologies that have the potential to speed up the discovery and utilization of new sources of disease resistance for wheat and barley. Technologies covered in the chapter include Focused identification of germplasm strategy (FIGS), speed breeding, Genome wide association studies (GWAS) and Genomic selection (GS).

The focus of Chapter 14 is the improvement of diagnostic techniques for disease identification in wheat and other cereal crops. Cereal pests and diseases can significantly reduce potential crop yields. Correct and timely identification in-field is key to their control. The chapter summarises and evaluates some of the many available methods for detection of pests and diseases, ranging from classical methods of plant pathology, such as visual or microscopic recognition, to new DNA sequencing technologies. The chapter discusses how protein-based diagnostics that rely on specificity of antibodies, such as variations on ELISA detection and dipstick or lateral flow devices, have been extended to protein

profiling by MALDI-TOF mass spectrometry. Nucleic acid-based amplification techniques using various forms of PCR are also now widely implemented, including isothermal amplification and in field pathogen detection. The chapter shows how the molecular diagnostic techniques are being rapidly supplemented with image-based diagnostics, which rely on hyperspectral imaging, applied via satellites or drones for regional or field scale monitoring of disease incidence and progression.

Moving from diagnostic techniques to disease control, Chapter 15 examines the role of natural antifungal compounds in controlling diseases in wheat and other cereals. Secondary metabolites are essential when considering the ecological context in which an organism operates. They have an array of functions, related to signalling and dealing with biotic and abiotic stress situations. For defence against pathogenic fungi, plants can synthesise various metabolites. Wheat, like several other cereals, produces various benzoxazinoids which are also associated with herbicide detoxification and the defence against herbivores and microorganisms. Apart from these benzoxazinoids, wheat seems to produce only a limited number of other metabolites with known antifungal activity when compared to other cereals. Nevertheless, wheat is still capable of successfully defending itself against pathogenic fungi by outsourcing its defences, i.e. through the mobilization of the microbial community. The chapter provides an overview of the way in which these natural antimicrobial compounds contribute to the defence of wheat against fungal pathogens, as well as considering the counter defensive actions undertaken by some of those fungal pathogens.

The volume's final chapter, Chapter 16, continues the theme of disease management by examining the role of tillage practices, rotations and intercropping in combatting diseases of wheat and other cereals. The great majority of modern agroecosystems comprise rotations of a small number of crop species where each year's crop is a genetically uniform monoculture. The narrow genetic basis for disease resistance in modern cultivars increases the potential for pathogens to overcome this resistance and attack a large number of plants at a similar state of development. The chapter presents a number of strategies for limiting foliar disease development in wheat and barley. The chapter discusses how crop rotations with non-cereal species can substantially reduce inoculum sources for residue-borne cereal leaf diseases. The chapter then examines other strategies, such as intercropping, gene deployment and conservation tillage. The chapter discusses the effectiveness of each strategy against particular foliar diseases. The chapter concludes that there is potential for residue-borne cereal leaf diseases to be managed under conservation tillage via crop rotation, fungicide application and careful choice of variety.

Index