BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of sugarcane

Volume 2: Breeding, pests and diseases

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Introduction

Sugarcane is the source of about three quarters of the world's sugar, and is grown widely in the tropics and sub-tropics. Despite rising demand, average yields have not increased significantly, partly because of continued vulnerability to pests and diseases. In addition, cultivation has been seen as damaging biodiversity and soil health with a negative effect on both yields and the environment.

These volumes on achieving sustainable cultivation of sugarcane summarise the wealth of research addressing these challenges. Volume 1 reviews cultivation techniques and sustainability issues. This volume, Volume 2 reviews how the challenges facing sugarcane production can be addressed through developments in breeding as well as better management of pests and diseases. The volume covers key advances in breeding, including conventional and molecular breeding techniques. It also summarises key advances in understanding bacterial, fungal and viral diseases of sugarcane and assesses best practices in integrated disease, pest and weed management.

Part 1 Plant physiology and breeding

The first part of the volume assesses the latest research on sugarcane genetics, physiology and genetic diversity, and how this is informing advances in conventional and molecular breeding techniques. The focus of Chapter 1 is on sugarcane genome sequencing and genetic mapping. The chapter explains the difficulties of sequencing and mapping the genome of sugarcane and strategies to overcome these difficulties. The chapter outlines progress on sugarcane sequencing, genetic mapping of simply inherited and complex traits. The chapter then focuses on the mapping of a gene controlling sugarcane brown rust resistance, *Bru*1, which exemplifies the potential of marker-assisted selection. Finally, the chapter discusses prospects for future research in sugarcane genome sequencing and genetic mapping.

Following on from the previous chapter's focus on sugarcane genomics, Chapter 2 examines advances in understanding sugarcane plant growth and physiology. Crop yield in sugarcane depends on how well the source leaves can supply the assimilates needed for the growth and filling of the harvestable plant. This is the source-sink relationship which remains poorly understood in sugarcane. The chapter discusses significant advances made in this area in the past few decades, as well as suggesting future trends in research such as high throughput genomic, metabolomic and phenotypic analyses that could allow refinement in crop and metabolic modelling, as well as improved breeding and production strategies.

Returning to the theme of the genetics of sugarcane, Chapter 3 examines the challenges of ensuring and exploiting the genetic diversity of sugarcane. The majority of cultivars in current commercial sugarcane breeding programs can be traced back to a few key interspecific hybrids that were developed during the early 1900s. Sugarcane breeders have expressed concerns about the narrow sampling of ancestral clones in modern sugarcane breeding programs, and this concern has prompted periodic attempts at so-called 'base-broadening' programs. The chapter provides an overview of sugarcane germplasm collections and then describes introgression-related research and breeding efforts focused on use of plant species belonging to the genera of *Saccharum*, *Erianthus* and others. It emphasizes the difficulties and challenges that need to be overcome in

order to achieve successful outcomes from introgression breeding, and considers a few possible future directions for research.

Chapter 4 shifts the focus to advances in conventional sugarcane breeding programs. All sugarcane cultivars currently grown throughout the world arise from breeding programs which have used a reasonably similar approach sustained over many decades. This approach comprises a continuous pipeline of regular (usually annual) crossing among selected parent clones to produce large populations of seedling clones, followed by selection of these clones in successive stages of field trials for 9–12 years for important traits. The chapter outlines the history and structure of sugarcane breeding programs as a context for considering efforts to advance rates of progress. The chapter reviews studies conducted in the last 30 years to improve many specific aspects of operations in sugarcane breeding programs. The chapter describes emerging concerns about whether current rates of genetic gain in sugarcane are optimal, and suggests some avenues for faster gains.

Continuing the theme of sugarcane breeding and complementing the preceding chapter, Chapter 5 considers advances in marker-assisted breeding of sugarcane. Sugarcane breeding has, until very recently, been based solely on phenotype, and marker-assisted breeding of sugarcane remains in its infancy compared with row crops such as maize and soybean. A major reason for this is the complex genetics of sugarcane. This chapter reviews the uses of DNA marker technology in sugarcane for fingerprinting and diversity analysis. This is followed by a review of the development of linkage maps and initial trait/QTL mapping, including the *Bru*1 locus for resistance to brown rust (*Puccinia melanocephala*). Finally, the chapter reviews the use of newer next generation sequencing (NGS)-based technologies in sugarcane, including genome-wide association analysis (GWAS) and genomic selection (GS).

Concluding the first part of the volume, Chapter 6 focusses on genetic improvement of sugarcane by transgenic, intragenic and genome editing technologies. The chapter explores the role of tissue culture, gene transfer and selectable marker systems in genetically improving sugarcane. It includes a detailed case study on transgenic, intragenic and genome editing approaches to improve bioethanol production from sugarcane. The chapter also addresses the role of metabolic engineering in elevating sucrose yields and producing alternative sugars or value-added biomaterials.

Part 2 Progress in understanding and managing diseases, pests and weeds

The second part of the volume discusses progress in understanding bacterial, fungal and viral diseases and their management, followed by the management of insect and nematode pests as well as weeds. Chapter 7 focusses on the challenge of ensuring biosecurity in sugarcane cultivation. Biosecurity is an important factor in maintaining and improving yields. It can refer to the day-to-day management of established pests, diseases, and weeds, as well as preparing for unusual threats to the industry, and safeguarding agriculture and natural resources. The chapter focuses on the sugarcane industry's preparedness for exotic pathogens, describing techniques such as pest risk analysis, quarantine control and surveys. The chapter discusses emerging technologies and examines and compares current guidelines. Finally, the chapter presents a case study of the 2006 sugarcane smut incursion in Australia.

Continuing the theme of understanding diseases of sugarcane, Chapter 8 addresses viral metagenomics and sugarcane pathogens. Plant viral metagenomics has recently proved effective for studying the collection of plant viruses. The advent of metagenomics-based approaches has led to the discovery and characterization of new plant viruses and helped solving etiological enigmas. The chapter describes the plant virus metagenomics methods developed during the last decade before focusing on the use and application of these approaches in the field of sugarcane pathology. The chapter presents three recent studies that have used viral metagenomics-based approaches aimed at solving long-standing etiological enigmas, identifying known and potentially new sugarcane viruses in a sugarcane quarantine context, and assessing the diversity of a known sugarcane virus (*Sugarcane yellow leaf virus*). Finally, the chapter discusses the challenges and opportunities of using such approaches to address issues of plant pathology.

Moving from viral to fungal diseases of sugarcane, Chapter 9 discusses progress in understanding fungal diseases affecting sugarcane, with a specific focus on red rot, a disease of sugarcane stalks caused by the fungal pathogen *Colletotrichum falcatum*. Red rot has been recorded in 77 countries worldwide, but occurs most severely in south Asian countries, especially India, Nepal, Pakistan, Myanmar and Bangladesh, as well as Thailand and Vietnam. Developing red rot-resistant varieties has been the major management strategy to deal with the disease in most countries. The chapter reviews the economic impact of red rot, diagnosis, pathogen variability, application of molecular tools to understand pathogen biology, varietal resistance, screening methods and new management approaches including fungicide delivery.

Complementing the previous chapter's focus on fungal diseases of sugarcane, Chapter 10 focuses on sugarcane smut. Fungal diseases of sugarcane constitute a worldwide threat to cultivation. Smut is caused by the biotrophic fungus *Sporisorium scitamineum*. After offering a historical perspective on the disease, the chapter presents an overview of data gathered over the past few years using 'omics' techniques (genomics, transcriptomics, proteomics and metabolomics) in combination with functional studies performed to identify candidate genes involved in the interaction between the pathogen and the host plant. The chapter discusses studies aimed at deciphering the molecular cross-talking between sugarcane and *Sporisorium scitamineum* along with new trends and recurring issues in the study of smut disease.

Continuing the theme of fungal diseases, Chapter 11 considers progress in understanding sugarcane rusts. Rust fungi (Uredinales or Pucciniales) are a globally distributed order of obligate parasitic fungi occurring on vascular plants. The typical symptom is a 'rust-coloured' (often orange or yellow) pustule on a plant leaf. Economically, rust fungi cause enormous crop losses, including in sugarcane. The chapter summarizes current knowledge of sugarcane rusts in terms of the relevant background biology, pathogen dispersal, disease identification, environmental conditions favouring disease emergence, crop loss, host-plant resistance and control measures. The chapter focuses on the history, identification and control of three rust diseases of sugarcane: brown, orange and tawny rust.

Chapter 12 moves from fungi to consider progress in understanding viruses affecting sugarcane. There are currently around ten diseases of sugarcane known to be caused by viruses. In recent years, our understanding of these diseases has greatly benefitted from access to low cost sequencing technologies which have revolutionised virus discovery, improved our understanding of genetic variation in viral populations, improved diagnostic options and helped us to understand gene functions and identify gene targets for control. The chapter addresses the broad themes of virus discovery, genetic variation, diagnostic

technologies and control. The chapter presents case studies describing the impact of two major viral diseases in Papua New Guinea and Indonesia.

Switching to bacterial diseases of sugarcane, Chapter 13 considers recent progress in understanding three major bacterial diseases: gumming, leaf scald and ratoon stunting. The chapter describes new insights provided by genomic and microscopy analyses of the bacterial pathogens *Xanthomonas vasicola* pv. *vasculorum, X. albilineans*, and *Leifsonia xyli* subsp. *xyli*, the causal agents of gumming, leaf scald, and ratoon stunting, respectively. The chapter addresses genomic-based hypotheses regarding adaptation of the three pathogens to sugarcane and the origin of their respective ancestors. It examines the strategies used by *X. albilineans* and *L. xyli* subsp. *xyli* to spread in sugarcane, including bacterial invasion of xylem vessels and non-vascular tissues. The chapter looks ahead to the development of further functional studies to improve the understanding of the interactions between sugarcane and bacterial pathogens, which are likely to contribute to better control of bacterial diseases of sugarcane.

Chapter 14 moves to consider the challenge of nematode pests of sugarcane by focussing on managing the soil biological community to improve soil health and reduce losses from nematode pests. Most sugarcane fields are infested with at least five species of plant-parasitic nematodes, with *Pratylenchus* and *Meloidogyne* considered the most damaging genera. The chapter describes the main nematode pests and the community of organisms with which they co-exist before analysing existing nematode control measures and their economic importance. The chapter then describes how a broader approach focusing on improving soil health can mitigate the impact of nematodes and ensure sustainable sugarcane production.

The theme of Chapter 15 is progress in understanding and managing insect pests affecting sugarcane. The chapter describes major achievements in pest management in sugarcane agroecosystems based on applied research conducted in different countries. The focus of the chapter is on two major groups of pests, stalk borers (Lepidoptera) and white grubs (Coleoptera). Chapter sections address determination of crop losses, biological control using parasitoids and entomopathogens, push-pull strategies with the use of companion (or service) plants, agricultural practices and their influence on pest population dynamics, insecticide use and biosecurity. The chapter also discusses new tools for pest detection and management such as modeling, remote sensing, and use of geographical information systems (GIS). The chapter looks ahead to future developments in integrated pest management of sugarcane.

Bringing together the insights of preceding chapters on particular diseases, Chapter 16 focuses on Integrated Disease Management (IDM) strategies in sugarcane cultivation. As has been noted, sugarcane diseases cause severe losses to sugar production around the world. More than a hundred bacterial, fungal, phytoplasma and viral diseases are present in sugarcane growing areas worldwide. Some diseases are present in most sugarcane growing regions while others are confined to specific countries. The chapter outlines and explores the various disease management strategies used in sugarcane cropping systems around the world and the potential for integrated disease management to minimize losses and maximize profitability. The chapter covers management of diseases by controlling the pathogens, management of diseases through the host, and management of diseases by controlling the environment, before looking ahead to future research trends in this field.

Complementing the preceding chapter's focus on integrated disease management, the volume's concluding chapter, Chapter 17, concentrates on the related challenges of Integrated Weed Management (IWM) in sugarcane cultivation. Weeds reduce sugarcane

yield by competing for water, nutrients and light. They may also act as alternate hosts for disease and insect pests, increase production costs and lower land value. Implementation of integrated weed management in sugarcane is essential for reducing the negative impact of weeds to economically acceptable levels. Understanding of the critical period of weed control is important so that IWM strategies can be developed to maximize control measures. The chapter deals with an integrated approach involving different methods for effective weed management in sugarcane that can be adopted for sustainable production, involving cultural, mechanical and chemical weed control.

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