BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of sorghum

Volume 1: Genetics, breeding and production techniques

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Introduction

Sorghum is one of the world's major cereals, cultivated in the semi-arid tropics for a growing range of uses, from food and feed to biofuel. Like other crops it faces the need to meet rising demand whilst reducing its environmental impact and adapting to the challenges of climate change. These challenges are addressed in the two volumes of: *Achieving sustainable cultivation of sorghum*:

- Volume 1 Genetics, breeding and production techniques
- Volume 2 Sorghum utilization around the world

The chapters in this volume (Volume 1) review key developments in breeding, from conventional to marker-assisted techniques, as well their application in developing higher-yielding, more stress-resistant varieties. The volume also discusses key research on making cultivation more efficient and sustainable, including ways of optimising nutrition, water, pest and weed management

Part 1 Sorghum the crop species

The first part of the book explores sorghum genetics. The theme of Chapter 1 is the classification and genetic diversity of sorghum, and the chapter presents a revised classification of sorghum. It sets out a generalized classification of cultivated sorghum from which a more precise working group can be defined to explain the variation within the chosen race. The classification is presented in a format that would be useful in breeding programs as breeders look to incorporate exotic germplasm into their breeding lines and hybrids.

Chapter 2 builds on the previous chapter's focus on genetic diversity by examining the comparative and evolutionary genomics of sorghum. Sorghum has a relatively small diploid genome, and retains much of the chromosomal structure and organization of its common ancestor. It also has multiple origins of domestication in different regions of Africa, resulting in a highly diverse germplasm well adapted to drought and other challenging environmental conditions. This makes sorghum ideal for dissecting the architectures of complex yet desirable traits. The chapter discusses what we know about the evolution and structure of the sorghum genome, the impact of domestication and the genetic architecture of key traits such as C_4 photosynthesis, drought and aluminium tolerance.

Maintaining the focus on genetic diversity, Chapter 3 looks at the challenge of ensuring the genetic diversity of sorghum. Sorghum is a staple food crop for millions of the poorest and most food-insecure people in the semi-arid tropics, and ensuring its diversity and conservation are therefore important for global food and nutritional security. The chapter discusses the taxonomy of sorghum, sorghum diversity and conservation, the factors shaping sorghum diversity, genomic prediction of sorghum landraces adaptation, and the use of cultivated and wild genes of sorghum to broaden the genetic base of sorghum cultivars.

Part 2 Sorghum improvement techniques

Part 2 reviews advances in conventional and marker-assisted breeding and their use to develop high-yielding and stress-resistant varieties. The subject of Chapter 4 is conventional breeding techniques for sorghum. The chapter describes a number of standard field operations, such as crossing, emasculation and harvesting, followed by a discussion of various methods of selection and topcrossing. After describing these classical breeding methodologies, the chapter evaluates new directions in sorghum breeding, such as the use of molecular markers and high-throughput means of phenotyping plants. The chapter concludes that, although classical breeding methodologies will continue to be a requirement in future, sorghum breeders will need to make use of evolving technologies if they are to be successful.

Chapter 5 moves beyond conventional breeding techniques to consider advanced technologies to accelerate sorghum breeding. The chapter provides an overview of the different types of molecular markers and describes techniques of marker-assisted selection in sorghum breeding, focusing on genomic selection, wide crosses and mutagenesis breeding. The chapter examines emerging technologies in the field, including doubled haploids, transgenic technology, genome editing and high-throughput phenotyping.

Complementing the preceding chapters, Chapter 6 looks at broader issues in harnessing genetic/genomic resources to improve sorghum yields. In spite of sorghum's inherent yield potential, its remarkable adaptation to marginal environments and its extensive use in various food applications by smallholders in developing countries, sorghum productivity has remained low. The chapter examines the major hurdles undermining sorghum productivity, including the constraints faced by smallholders.The chapter addresses how the gap in yield potential might be bridged in such areas as optimizing plant architecture through unlocking heterosis to produce more vigorous hybrids.

Chapter 7 examines sorghum breeding for biotic stress tolerance. Sorghum breeding is poised to take advantage of remarkable advances in genomics and molecular technologies. While, as Chapter 5 points out, classical breeding methods have been successful in identifying and incorporating resistance to biotic stresses, Chapter 7 focusses on the application of the new tools and technologies that can simplify and accelerate breeding of improved sorghum varieties. The chapter documents current genetic sources of resistance which can be exploited by rapidly developing techniques such as gene editing and gene transfer. The chapter reviews recent developments in dealing with major biotic stresses of sorghum, including diseases (fungal, bacterial and viral), insect pests, *Striga* (witchweed), and nematodes. The chapter also considers the structure and function of resistance or 'R' genes and their deployment.

The subject of Chapter 8 is sorghum breeding for abiotic stress tolerance. Globally, domesticated sorghum is often grown on marginal lands and in environments exposing the plant to temperature extremes and water deficits. Although sorghum exhibits better abiotic stress tolerances than many crops, significant sorghum yield losses are experienced annually in response to unfavorable environments. The chapter focuses on methods for identifying diversity among germplasm collections. It then explores ways of exploiting germplasm diversity to improve soybean responses to temperature and water-deficit stress. The chapter looks at the challenge of identifying quantitative trait loci (QTL) for post-flowering drought tolerance and presents a number of case studies in improving drought tolerance.

Turning to another specific application of breeding technologies, Chapter 9 examines sorghum's tolerance of low phosphorus soil conditions. Many sorghum-growing areas in Africa are affected by phosphorus (P) scarcity. In these areas small-scale farmers depend

on sorghum for food security and income, but have difficulty accessing or paying for P fertilizer. With the expected future price increases for P fertilizer, this problem is likely to increase. Enhancing sorghum tolerance to low P soil conditions is therefore of great importance both now and for the future. The chapter first gives an overview of the worldwide P challenge, and then focuses on the challenges of breeding sorghum for low soil P conditions, taking breeding for smallholder farmers in West Africa as a case study. The chapter summarizes the implications for applied sorghum breeding in West Africa, and reviews the future trends and challenges (both breeding and agronomic/socioeconomic) in bringing benefits of sorghum low-P tolerance to West African farmers.

The concluding chapter of the section, Chapter 10, examines advanced testing, multiplication and the release of new sorghum varieties. The chapter focuses especially on hybrid evaluation and release. The release of a new sorghum variety or hybrid is the culmination of many years of breeding and evaluation. The chapter describes the hybrid advancement process, including ways of increasing the parent lines for hybrid production and the guidelines that must be followed to ensure high quality seed. The chapter also examines procedures for registration, certification, plant variety protection and plant patenting.

Part 3 Sorghum production techniques

The final part of the book discusses ways of improving cultivation to make the most of new varieties, from nutrient and water management to better control of diseases, insects and weeds. Chapter 11 provides an overview of improving sorghum crop management. Sorghum is a versatile crop, produced in more than 100 countries. However, the productivity of sorghum in developing countries is much lower than developed countries, due to non-adoption of improved crop management practices. The chapter describes a variety of standard crop management techniques, including discussion of optimum planting conditions and the management of nutrients and water, and considers how practices may differ across major sorghum-producing areas such as India, West Africa, Australia and the USA. The chapter concludes that greatly improved yields can be obtained by matching genotype with environment and using best management practices.

Building on Chapter 11, the subject of Chapter 12 is improving soil and crop nutrition management in sorghum cultivation. The chapter provides an overview of the nutrients needed, quantities used and concepts of nutrient management commonly utilized in commercial grain sorghum production. The chapter describes how these concepts can also be applied to subsistence production as practiced in much of the developing world where sorghum is grown. The chapter's focus is on the management practices and tools utilized for the essential mineral nutrients commonly observed to be deficient in sorghum production, including N, P, K, S, Fe, Mn, Zn, and Cl. The chapter discusses soils and conditions where deficiencies may occur and, tools to access nutrient availability. It also reviews nutrient sources, from chemical fertilizers to common byproducts which can be used as nutrient sources, as well as timing and application methods.

Moving from soil conditions to water use, Chapter 13 looks at the challenge of improving water management in sorghum cultivation. Sorghum's deep, fibrous root system provides greater root volume and therefore potential access to a greater soil water volume enabling sorghum to withstand greater periods of water stress if there is ample stored soil water. The chapter examines dryland production of sorghum and sorghum irrigation methods,

including deficit irrigation. The chapter also addresses the relationship between soils and irrigation management.

Chapter 14 moves from management of soil and water to consider the management of insect pests in sorghum cultivation. Integrated pest management (IPM) is a practical approach that uses a combination of methods, including cultural, biological, and chemical controls, to keep pest abundance or damage below economic loss. The chapter describes ways of preventing damaging infestations, as well as evaluating pest abundance and damage to determine when remedial action with insecticide is justified. The chapter describes key insect pests, their life cycles and impact on sorghum crops, with a particular focus on the USA but also considering other countries. The chapter also examines the contribution of beneficial insects.

The theme of Chapter 15 is diseases of sorghum, with a focus on seedling, seed, panicle and foliar diseases. As sorghum continues to grow in significance in large parts of the world, attention is given to the many different types of disease that can affect this crop, and how they might be successfully avoided or managed. All physical structures and tissues of the sorghum plant may become diseased with one pathogen or another, and different diseases can damage the plant at virtually every stage of growth. The chapter provides a comprehensive overview of the main diseases affecting sorghum, describing the different conditions in which they proliferate, their common symptoms, and their impact on crop yield. In each case, the chapter discusses the potential for host resistance and provides information regarding effective disease management.

Continuing the theme of disease management, Chapter 16 considers diseases of sorghum affecting the plant's stalk and root, as well as other diseases. Of all the diseases affecting sorghum, root and stalk diseases are among the most damaging and difficult to control. This is due to their hidden nature, and the fact that their symptoms often resemble abiotic stressors such as drought or freeze damage. The chapter presents an overview of some of the main bacterial, viral and parasitic diseases affecting sorghum root and stalk, describing their common symptoms, environments and typical effects on yield. In each case, the chapter offers recommendations for effective management of the disease, including information regarding tillage practices, fertilizer rates, crop rotation and use of fungicides.

Chapter 17 focuses on weed management in sorghum cultivation. Sorghum remains an important crop particularly in marginal environments due to its low input requirements and high resilience. Weed management is a key production challenge for sorghum, and the herbicide tools available are very limited, particularly for postemergence control of grass weeds. Weedy relatives such as shattercane and johnsongrass present challenges for selective control in sorghum due to genetic similarities. The chapter presents a number of weed management options for sorghum, including identifying critical periods for weed control, with a particular emphasis on preemergence control of grasses and other tough-to-control annual weeds. The chapter concludes that an integrated weed management approach, encompassing a strategic application of pre- and post-emergence herbicides used in combination with non-chemical tactics, will be critical to achieving sustainable weed management in sorghum.

The final chapter in the book, Chapter 18, considers the management of sorghum after harvesting. Sorghum is a versatile crop that has many post-harvest uses. After describing post-production operations in dealing with sorghum, the chapter examines techniques for the transformation of sorghum grain and the variety of resulting sorghum products. Finally, the chapter looks at requirements for sorghum export and quality assurance.

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