BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of grain legumes

Volume 1: Advances in breeding and cultivation techniques

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Introduction

Grain legumes are widely cultivated, particularly for their dry seeds (known as pulses). They include common beans and lentil which are grown globally, as well as regionally-specific types of pulses such as cowpea, faba beans and pigeonpea. The FAO defines pulses as crop plant members of the *Leguminosae* family (commonly known as the pea family) that produce edible seeds. In this definition, only legumes harvested for dry grain are classified as pulses, excluding species such as soybean and groundnut. However, broader definitions of grain legumes include groundnut and soybean as well.

Grain legumes are important in the developing world for a number of reasons. They are a rich source of protein and fibre, minerals and vitamins. In addition, their rapid growth and ability to fix nitrogen and improve soil health makes them a key rotation crop in the sustainable intensification and diversification of smallholder farming. This makes grain legumes a key food security crop. However, yields in developing countries are low as a result of such factors as the need for improved varieties of seed, poor seed distribution, the impact of pests and diseases, as well as vulnerability to poor soils, drought and other effects of climate change. There is now a rich body of research addressing these challenges.

The challenges facing grain legumes are addressed in the two volumes of *Achieving sustainable cultivation of grain legumes*:

- Volume 1 Advances in breeding and cultivation techniques
- Volume 2 Improving cultivation of particular grain legumes

This volume (Volume 1) focussing on breeding and cultivation. The volume reviews key developments in understanding crop physiology and genetic diversity as well as breeding. The book also covers advances in grain legume cultivation, from variety selection to post-harvest storage, and discusses the latest trends in disease, insect pest and weed management.

Part 1 Plant physiology and breeding

The first part of the volume summarises advances in understanding crop physiology and genetic diversity, and examines how this understanding has informed the development of new varieties. Chapter 1 discusses advances in understanding grain legume physiology, with a particular focus on stomatal behaviour and the plant's response to abiotic stress. Grain legumes can fulfill several roles. A potential constraint on their use is their response to drought in the more arid conditions predicted in some parts of the world due to climate change. The chapter reviews the responses of various grain legumes to water deficit conditions, and then discusses how grain legumes can be bred for the stomatal characteristics most appropriate for water-scarce environments.

Chapter 2 continues the previous chapter's focus on advances in understanding grain legume physiology, focusing on how root system architecture (RSA) influences root foraging and resource uptake from the soil. RSA thus determines plant growth and productivity in grain legumes. Understanding RSA, nutrient uptake and its response to drought and other abiotic stresses is vital for breeding super genotypes for efficient water and nutrient acquisition and with enhanced adaptation to abiotic stresses. The chapter describes the role of root architecture in plant health, available approaches for measuring root architecture, variability of RSA traits across genotypes and its implications for breeding drought-resistant varieties. The chapter explains how combined root phenotyping, non-destructive imaging, root model simulations and molecular techniques can serve as tools in breeding legume genotypes with optimised root system for enhanced adaptation to target environments.

Chapter 3 moves from the physiology of grain legumes to their genetics, and concentrates on the challenge of exploiting the genetic diversity of grain legumes. An increase in the production and marketing of grain legumes would help to diversify diets and improve human nutrition, as well as contributing to the sustainability of cropping systems and long-term soil health. However, the projected impacts of climate change, as well as existing constraints in cultivation, pose challenges to increasing production. One of the key resources for meeting these challenges is conserving genetic diversity for crop improvement, whether *ex situ* in genebanks and *in situ* with farmers or in protected areas. The chapter reviews global strategies to assess the status of the major grain legume genetic resources held in *ex situ* collections, develop a vision of a more secure global system of conservation, and identify priorities to facilitate the establishment of this global system. As an example, the chapter focuses on the characterization and exploitation of the genetic resources of chickpea and pigeonpea.

Complementing the previous chapter's insights into genetics, Chapter 4 looks at advanced breeding techniques for grain legumes. The challenge of grain legume production is to continue increasing productivity while reducing the significant seed yield gap between developed and developing countries/regions. Advanced breeding techniques have an important role to play in the era of genomics. The chapter describes the main grain legume breeding programs, including breeding targets such as stressors and phenotypes. The chapter examines grain legume reference genome sequences, legume common lineages and synteny, and describes the use of whole-genome and reduced representation resequencing and SNP chips to identify target traits.

Going beyond the advanced breeding techniques discussed in the preceding chapter, Chapter 5 addresses the genetic modification of grain legumes. Most grain legumes are grown predominantly in the low-input production systems in the developing countries of Asia and Africa and are subject to various production constraints. The chapter addresses progress in and prospects for transgenic interventions in the improvement of grain legumes, concentrating on chickpea, pigeonpea, cowpea, lentils, peas, peanuts and other grain legumes. The chapter examines the key challenges in the commercialization of genetically-engineered grain legumes, and shows how these technological interventions provide opportunities for enhancing efficiency and effectiveness of breeding programs for complex traits, as well as increasing the rate of genetic gain in grain legumes.

The focus of Chapter 6 is specifically on using breeding and genetic engineering techniques to develop drought- and heat-tolerant varieties of grain legume. Despite the complexity imposed by the polygenic nature of plant tolerance to drought and to heat, significant strides have been made in understanding the underlying response and adaptation of plants to these stresses. Together with advanced and accessible technologies such as next-generation sequencing and precision phenotyping, this has enabled the assembly of molecular and physiological tools in grain legumes that support the development of tolerance through traditional and molecular breeding. The chapter provides an overview of physiological, biochemical and molecular responses and adaptation mechanisms to drought, and to heat, with specific examples from grain legumes. It examines traditional breeding and the utilization of natural genetic diversity, developments in molecular breeding including the identification of genetic associations and quantitative trait loci (QTL) and functional genomics studies on stress-relevant candidate genes or gene families. Finally, the chapter discusses critical contemporary considerations to strengthen research on developing tolerance to drought and heat.

Complementing the previous chapter's focus on drought- and heat-tolerance, Chapter 7 examines another specific application of breeding and genetic engineering techniques in developing pest- and disease-resistant varieties of grain legume. Average yields of most grain legumes are still relatively low due in part to susceptibility to pests and diseases. The chapter explores current advances in developing pest- and disease-resistant cultivars of a variety of grain legume crops, including faba beans, peas, lentils, chickpeas, grass peas and common beans. The chapter focuses, in particular, on breeding cultivars less susceptible to foliar diseases caused by biotrophic or necrotrophic pathogens, soil borne diseases, as well as nematodes, bacteria, insect pests and parasitic weeds.

The concluding chapter of this section, Chapter 8, considers the bio-fortification of grain legumes. Micronutrient malnutrition (MNM) is one of the world's major health threats. Iron (Fe) and zinc (Zn) deficiencies affect more than a third of the world's population, particularly women and children. Biofortified legume crops are being developed with higher levels of bioavailable Fe and Zn to alleviate MNM and improve the nutritional status of affected populations. The chapter reviews the genetic variability of Fe and Zn content in many legume crops, and shows how this is being used to guide breeding as well as improve agronomic management.

Part 2 Cultivation

The second part of the volume reviews improvements in cultivation techniques to make the most of these new varieties, from variety selection and seed quality management, through pest and disease management to storage and quality assessment. The focus of Chapter 9 is on variety selection and seed quality management in grain legume cultivation. The chapter examines the key issues and challenges in variety selection and quality control. The chapter also includes some detailed case studies on how research has been used to improve legume cultivation in practice.

Chapter 10 examines grain legumes in integrated crop management systems. The chapter looks at how integrated crop management strategies can be used to increase grain legume production in rainfed, resource-poor farming systems. Generally, grain legumes fail to reach even half of their potential yields in these systems. For rainfed grain legumes the major contributor to the yield gap is sub-optimal soil moisture, along with a suite of nutrient, pest and disease constraints. The challenge is to identify remedial action within the means of resource-poor farmers. This requires greater emphasis on farmer-participatory research to identify local constraints, and engaging farmers in testing locally feasible solutions. Examples of this approach are documented in the chapter. Particular areas in need of intensive on-farm research include adapting grain legume farming to conservation agriculture and exploring means to increase cropping intensity of grain legumes in cereal-dominated cropping systems. The chapter suggests that a concerted shift in international and national efforts to support farmer-participatory approaches is needed.

Complementing Chapter 10, Chapter 11 focuses on the challenge of ensuring sustainable grain legume-cereal cropping systems. There is currently renewed interest in intercropping in Europe in order to achieve sustainable, ecological or eco-functional intensification of agricultural production, particularly in organic farming. The chapter summarises data from over 50 field experiments undertaken since 2001 on cereal-grain legume intercropping in 13 sites in southern and western France as well as in Denmark using spring and winter cereal-grain legume intercrops. The chapter also addresses the effects of intercropping on yields and quality, the agronomical performance of intercropping and cultivation practices in intercropping.

Continuing the theme of integrated cultivation strategies, Chapter 12 goes on to consider soil and nutrient management in grain legume cultivation. Due to their role in improving soil fertility, grain legumes can be integrated into farming systems as part of soil fertility management. This offers a potential pathway towards sustainable intensification. The chapter focuses on how to maximize biological nitrogen fixation and yields of grain legumes through soil and nutrient management practices. These techniques are illustrated in practice through a case study looking at biological nitrogen fixation in the Guinea Savanna zone of Ghana.

Chapter 13 considers a major challenge to integrated management, namely diseases affecting grain legumes and their management. The chapter reviews the main grain legume diseases before considering the relative benefits and disadvantages of both traditional and integrated disease management techniques. The chapter reviews the components of integrated disease management and practical developments in the field, with a particular focus on modelling, sampling and identification. Finally, the chapter considers advanced and rapid analysis techniques in integrated disease management.

Moving from integrated disease management to integrated pest management (IPM), Chapter 14 addresses insect pests and integrated pest management techniques in grain legume cultivation. As an example, it focuses on cowpea, a staple legume food crop grown and consumed in the dry savanna regions of sub-Saharan West Africa. The chapter describes the pests that attack cowpea at every stage of its development, including aphids, thrips, pod sucking bugs, and lepidopteran pod borers. The chapter reviews current control measures and their limitations. It then discusses ways of developing IPM strategies by exploiting knowledge of pest biology, host plant resistance (including *Bt* cowpea) and biocontrol. The chapter also emphasises the importance of disseminating new information effectively to farmers using cell phone technology, discussing the example of Scientific Animations Without Borders (SAWBO) which uses cell phones to distribute downloadable video content.

Complementing the focus of the previous chapters on diseases and pests, Chapter 15 moves on to look at weed management in grain legume cultivation. Managing weeds in a grain legume crop is critical for obtaining optimum yield. All grain legumes are relatively poor competitors with weeds and thus are prone to yield reductions when grown in the presence of weeds. The chapter outlines the nature and challenges of weed interference with crop growth and methods of weed control, as well as offering two detailed case studies. The chapter demonstrates that a combination of practices, such as cultivar selection, planting date, tillage system, in-crop tillage or cultivation, and/or herbicides is needed to increase the likelihood of successful weed control.

The theme of Chapter 16 is the challenge of grain legume storage in developing countries. Grain stored after harvest is often subject to major quantitative and qualitative losses. The major cause of loss is storage insects and mycotoxin-producing organisms, which reduce the nutritional and monetary value of the grain. The chapter describes various methods of storage-insect control that have the potential to help farmers with limited resources.

Complementing the previous chapter, Chapter 17 concentrates on the drying, handling, storing and quality monitoring of pulses. The chapter discusses how drying, storage and handling can adversely affect the quality of pulses. It reviews how pulse quality is assessed, and discusses strategies for pulse drying, handling and storage in order to maintain quality. The chapter describes techniques for grain monitoring and automated aeration control, as well as non-destructive techniques for quality assessment of pulses, including colour and hyperspectral imaging.

Continuing the focus on quality, Chapter 18 reviews the dietary health benefits and anti-nutritional factors in grain legumes. Legumes are a significant source of essential nutrients including dietary fiber, protein, dietary minerals, and carbohydrates. Abundant in both soluble and insoluble fiber, legumes support colonic and overall health. The chapter describes the effect of grain legume consumption in combatting gut inflammation, the health benefits of dietary fiber, and possible connections between dry grain legume consumption and carcinogenesis. The chapter also explores possible chemical toxicant exposure from grain legume consumption.

The final chapter in the book, Chapter 19, also assesses the nutritional quality of grain legumes, but from an economic perspective. It discusses the potential economic value that can potentially be derived from exploiting the nutritional potential of grain legumes. It assesses current constraints on production, including constraints in the availability of credit, inputs and information on best practice. It also reviews ways of changing consumer behaviour to boost demand to allow the expansion of grain legume cultivation.

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