BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of maize

Volume 1: From improved varieties to local applications

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Introduction

Maize is one of the most widely grown crops in the world, both for food and livestock feed, biofuels and other uses. Cultivated on 184 million hectares globally, maize is cultivated in 160 countries throughout the continents of America, Europe, Oceania, Africa and Asia. Maize is fundamental to global food and economic security, providing up to 30% of total calorie intake in some developing countries. It has been estimated that maize yields need to increase by 60% by 2050 in the context of increasing competition for land, water, energy and labour. Maize production is currently held back by factors such as: lack of available improved cultivars or failure to take up new improved varieties, inadequate crop management and storage, poor soil quality, the impact of pests and diseases and more extreme weather related to climate change. Research needs to focus on supporting more productive, sustainable and nutritionally valuable maize cultivation, particularly for smallholders in the developing world.

The two volumes of *Achieving sustainable cultivation of maize* summarise key research addressing these challenges. This volume focuses on breeding, improving nutritional quality and ways of supporting smallholders. Volume 2 looks at ways of improving maize cultivation as well as the management of pests and diseases.

Part 1 Genetic diversity and breeding

It is widely accepted that developing improved varieties which are more resilient to pests, diseases and extreme weather depends on preserving and exploiting genetic diversity in maize. As Chapter 1 points out, genebanks and *ex situ* collections are essential to conserving genetic diversity and enabling global access to those resources. The chapter provides a comprehensive and authoritative review of the key issues facing both *in situ* and *ex situ* collections. These issues include better conservation and exploitation of wild varieties and landraces, as well as identifying broader genetic and allelic diversity in *Zea* and *Tripsacum*. The chapter includes case studies of the use of exotic germplasm to support breeding of more resilient varieties. As Chapter 1 argues, the future role of genebanks must continue to evolve from the initial concept as an emergency and long-term repository of genetic diversity which otherwise would be lost. Genebanks should occupy a pivotal point in the global flow of germplasm, facilitating both conservation and providing access for use, as well as providing characterisation data on accessions to support breeding programmes.

Building on Chapter 1, Chapter 2 provides a review of key challenges in breeding programmes. The chapter focuses specifically on the challenges facing breeding programmes in sub-Saharan Africa which are critical to meeting the need for new varieties suited to local conditions. An example is screening new varieties for drought tolerance season under carefully monitored conditions of water stress. However, most national agricultural research system (NARS) research stations in African countries do not have the necessary weather stations and irrigation systems to conduct high-quality research in order to develop drought-resistant varieties and boost maize production in the region. Similarly, for national programmes to make full use of methods such as doubled haploid (DH) techniques or marker-assisted selection (MAS), adequately equipped facilities are required and appropriately trained scientist/personnel must be available.

As well as looking at what is needed to improve infrastructure and personnel, the chapter explores developments such as the improved use of broader germplasm resources in African breeding programmes. As an example, and echoing Chapter 1, it shows how *Striga* tolerance in maize germplasm has been increased by introgression of favourable genes from teosinte (*Zea diploperennis*), a wild relative of maize. It also discusses advances in hybrid development in the areas of heterotic grouping and identification of testers in maize germplasm and the potential of participatory plant breeding research, including innovations such as mother-baby trials (MBTs). An MBT involves evaluating a relatively large number of potential new varieties in a trial (mother trial) and subsets of the varieties (baby trials) in satellite farmers' fields. MBTs have been shown to encourage better interaction between researchers and farmers, resulting in better targeted and adopted varieties for local conditions. They illustrate the potential of African breeding programmes given appropriate support.

Picking up on themes in both Chapters 1 and 2, Chapter 3 looks at key challenges facing breeders in an era of climate change. As the chapter points out, inbred-hybrid techniques are still widely used in maize breeding but have resulted in a decline in genetic diversity and have sometimes focused too much on breeding for ideal environmental conditions. Only maize breeding programmes utilising large samples of genetically broad-based germplasm have the potential to contribute useful and unique alleles to improve abiotic and biotic stress tolerance. There is also a need for breeders to improve techniques for developing traits which are genetically complex, difficult to screen and largely influenced by the environment. The chapter includes case studies addressing the challenge of using exotic germplasm and improved techniques to develop more resilient varieties such as short-season quality maize hybrids, as well as cold and drought-resistant varieties.

Chapter 4 provides a case study of cutting-edge developments in maize breeding, focusing on improving protein content in maize. The chapter reviews the mechanisms that limit the supply and quality of protein, including transcriptional and post-transcriptional regulation of gene expression. It looks in particular at the regulation of storage protein genes, particularly the synthesis and deposition of zein proteins. It also describes mutants in maize that interfere with these mechanisms and how genetic approaches can improve protein quality traits, including ways of maintaining sulphur and nitrogen storage in maize seeds.

The following two chapters illustrate how developments in breeding can be used to target and improve particular traits in maize. Depending on the growing environment, maize grains can be infected by one or more ear rot fungi which may decrease grain yield and quality. Many of them also produce secondary metabolites, known as mycotoxins, which can have serious detrimental effects on humans and animals that consume the infected grain. The successful creation of maize germplasm with resistance to aflatoxin infection requires the identification of genetic variation for resistance in maize germplasm, techniques to identify and quantify resistance, and breeding methods or procedures to develop resistant lines. Chapter 5 looks at these challenges in developing new varieties, and how they have been addressed in practice in creating *Aspergillus flavus*-resistant maize breeding lines.

In the light of more extreme weather conditions associated with climate change, Chapter 6 looks at research on developing cold-resistant maize varieties. This chapter discusses the physiological and genetic background of cold tolerance, the methodology required for its analysis, and ways of improving cold tolerance by breeding. It begins by reviewing research on the effects of temperature on maize growth, as well as factors affecting seed quality and germination at low temperatures. It goes on to discuss germplasm evaluation and the Inheritance of cold tolerance before showing how chilling-tolerant hybrids have been developed by selecting for inbred lines with good early or seedling chilling tolerance. The increasingly widespread use of molecular breeding methods, MAS and the discovery of quantitative trait loci (QTLs) linked to chilling tolerance are helping to shorten the breeding process.

Part 2 Understanding and improving maize nutritional and processing quality

As indicated at the beginning of the Introduction, maize is a critical part of the diet in many developing countries. Improving its nutritional quality is an important target in improving health. Chapter 7 reviews what we know about the protein content of maize, including a discussion of how protein quality can be enhanced by the incorporation of the *opaque-2* gene into elite maize germplasm in order to enhance lysine content. Subsequent sections review the carbohydrate profile of maize, the qualities and uses of corn oil and the micronutrients present in maize.

Building on Chapter 7, Chapter 8 looks at ways of enhancing the micronutrient density of maize through biofortification. The chapter assesses options for biofortification of maize with provitamin A carotenoids, and looks at methods for breeding of provitamin A biofortified maize and the ways it can be delivered to consumers. The chapter includes a case study of the maize biofortification programme in Zambia.

Developing themes in Chapter 4, Chapter 9 looks at ways of improving the starch and protein content of maize. After reviewing maize kernel composition, it provides an overview of methods for improving the protein and starch content of maize kernels. The chapter then goes on to summarise methods for improving the protein and starch content of maize using mutant lines. It also discusses ways of improving the digestibility of maize protein and starch, as well as assessing and reducing the anti-nutritional properties of maize.

Advances in the technologies and methods for analysing the quality characteristics of maize grains can help us to determine the contribution of maize products to human health, as well as helping in the development of maize cultivars with improved characteristics. Chapter 10 reviews the current range of methods for determining important characteristics of maize grains, with sections covering starch content, protein content, phenolic compounds (in particular flavonoids such as carotenoids), kernel hardness/texture and levels of myotoxins.

Part 3 Translating research into practice: improving maize cultivation in the developing world

The final group of chapters focus on ways of translating the results of research into practical outcomes that can benefit farmers, particularly smallholders in developing countries. The adoption of improved technology is essential for increasing productivity in the production of maize in Africa. Chapter 11 reviews the importance of increasing the adoption rate of improved maize technologies, especially among smallholder farming households. It reviews current research on understanding farmers' decisions on whether or not to adopt new technology. It then assesses economic and institutional factors which make adoption difficult, such as land availability, lack of capital, price fluctuations, poor seed supply and infrastructure. It also looks at farmer characteristics and attitudes, which affect adoption such as objectives and goals as well as perceptions of costs and risks associated with adopting new methods and technology. The chapter concludes by looking at practical strategies for improving the adoption of improved maize technologies.

One of the reasons that adoption of new varieties, cultivation techniques or technologies can be poor is the nature of implementation. Paradigms of agricultural innovation have shifted considerably from linear Transfer-of-Technology (ToT) models to 'Farmer First' and Farming Systems Research and, most recently, to the use of Agricultural Innovation Systems (AIS). An innovation system can be defined as a network of organisations, enterprises and individuals focused on bringing new products, new processes and new forms of organisation into use, together with the institutions and policies that affect their behaviour and performance. The agriculture innovation systems framework maintains that improved interaction and joint work between stakeholders result in better information exchange, and more ideas and opportunities for sector improvement. This, in turn, leads to further collaboration and more opportunities for better and faster innovation. Chapter 12 presents an AIS approach to improving innovation in maize production. The chapter considers three important stages of an innovation process: the identification of problems and targeting of interventions, local experimentation, and bringing new ideas into routine use. The chapter discusses the role of research at each stage, and then argue that an AIS approach mandates increased focus on the personal, organisation and institutional capacities of researchers and research bodies.

The final chapter in the book looks at the role of women in maize cultivation. Woman farmers are less likely to use improved technologies for maize production than are their male counterparts. Gender analysis is therefore essential in guiding the design and focus of research to ensure that women participate in and benefit from growth in the maize sector. Chapter 13 begins by analysing the way farming households manage maize cultivation. The following section analyses the ways in which gender impacts agricultural production systems, including access to resources and decisions about inputs. The next three sections offer a detailed analysis of the impact of gender on three vital aspects of maize production: labour, processing and storage and varietal choice. The preferences of women as urban consumers are also considered. Finally, a brief discussion of the Women's Empowerment in Agriculture Index highlights one tool for monitoring the impact of research and agricultural change on women's empowerment.

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