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Achieving sustainable cultivation of cocoa

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Introduction

There is a growing global demand for cocoa. However, cultivation is dependent on ageing trees with low yields and increasing vulnerability to disease. There is also growing concern about the environmental impact of cultivation in such areas as soil health and biodiversity. There is therefore an urgent need to make cocoa cultivation more efficient and sustainable to ensure a successful future. These challenges are addressed in *Achieving sustainable cultivation of cocoa*.

Part 1 reviews genetic resources and developments in breeding. Part 2 discusses optimising cultivation techniques to make the most of new varieties. Part 3 summaries the latest research on understanding and combatting the major fungal and viral diseases affecting cocoa. Part 4 covers safety and quality issues whilst the final part of the book looks at ways of improving sustainability, including the role of agroforestry, organic cultivation and ways of supporting smallholders.

Part 1 Genetic resources and breeding

The first part of the volume reviews genetic resources and developments in breeding. Chapter 1 discusses the origins of cacao as well as the taxonomy and classification of the varieties of *Theobroma*. The chapter then reviews the distinctive characteristics of the three main varieties of *Theobroma*: Criollo, Forastero and Trinitario.

Moving on from classification and taxonomy to genetics, the subject of Chapter 2 is the key challenges of conserving and exploiting cocoa genetic resources. The future of the world cocoa economy depends on the availability of genetic diversity and the sustainable use of this broad genetic base to breed improved varieties. Decreasing cacao genetic diversity (whether conserved *in-situ*, on farms or in *ex-situ* collections) is a serious problem which needs to be urgently addressed. A Global Strategy was published in 2012 to optimize the conservation and maximize the use of cacao genetic resources as the foundation of a sustainable cocoa economy. The chapter describes the key challenges in delivering this strategy, how they are being addressed and the priorities for further research and actions. These include securing existing *ex-situ* cacao genetic resources, developing a global strategic cacao collection, and collecting and gap filling in *ex-situ* collections to reflect genetic diversity. The chapter also looks at the importance of ensuring the *in-situ* and on-farm conservation of important diversity, strengthening the distribution and safe movement of germplasm, improving the use of cacao genetic resources, and improving documentation and sharing of information. Some of these issues are discussed in more detail in the following three chapters.

Building on the previous chapter, Chapter 3 focuses specifically on the role of gene banks in preserving the genetic diversity of cacao. The centre of diversity of cacao in South America is characterized by genetic erosion from deforestation, but fortunately a wealth of genetic diversity exists in global cacao collections. The chapter discusses the role and types of gene banks to capture genetic diversity. The chapter deals with the distinction between cacao gene banks and other gene banks and examines how this affects the management and estimation of genetic diversity. The chapter advocates a SNP panel for fingerprinting, and addresses molecular marker-assisted management with the objective of comparing global collections and formulating a core collection.

Complementing the themes of the preceding two chapters, Chapter 4 concentrates on the safe handling and movement of cocoa germplasm for breeding. Movement of cocoa germplasm is often required in breeding programmes to increase the genetic diversity pool or for the testing of clones/progeny in the field. However, such movement risks the spread of pests and diseases, many of which are confined to particular geographical locations. It is therefore critical that movement of germplasm is conducted within a quarantine framework. The chapter reviews the risks associated with the movement of cocoa germplasm. It considers international governance of plant movement before discussing the work of the International Cocoa Quarantine Centre at the University of Reading as a hub for international movement of cocoa germplasm.

The final chapter of the section, Chapter 5, covers developments in cacao breeding programmes in Africa and the Americas. The chapter explores the main developments obtained as a result of cacao breeding programmes in Trinidad, Brazil, Ecuador and Costa Rica in the Americas and in Ghana, Côte d'Ivoire, Nigeria and Cameroon in Africa. The chapter describes the different types of commercial cacao cultivars and the breeding objectives of the programmes. It examines heterosis and heterotic groups in cacao and explores the contrast between 'traditional' and new cacao breeding methods. Finally, the chapter examines the issue of breeding cacao for organoleptic quality.

Part 2 Cultivation techniques

The second part of the volume discusses optimising cultivation techniques to make the most of new varieties. The theme of Chapter 6 is cocoa plant propagation techniques. The availability of high performance planting materials to cocoa farmers is an important part of a package of measures to improve the productivity of cocoa farms and thus the sustainability of the cocoa economy. The chapter reviews the methods, advantages and challenges of techniques of mass propagation, with a focus on seed and conventional vegetative propagation (tissue culture techniques are covered in the following chapter). The chapter discusses key challenges in supplying farmers with improved planting materials. These include availability of source materials, personnel and infrastructure requirements, phytosanitary considerations, costs and levels of demand.

Continuing the theme of propagation, Chapter 7 examines the potential of somatic embryogenesis (SE) for commercial-scale propagation of elite cacao varieties. Plant tissue culture can be used to speed up the development and deployment of genetically-improved genotypes. Research conducted by multiple groups for over 25 years has led to the development of protocols for efficient somatic embryogenesis of cacao. The chapter provides a synthesis of this research on cacao tissue culture methods and field-test evaluations of SE-derived plants. The chapter also reviews current activities by cacao-producing countries in large-scale propagation of important genotypes, with case studies from Africa, Asia and the Americas.

Moving on to agronomic practices, Chapter 8 focuses on the achievement of good agronomic practices in cocoa cultivation and the rehabilitation of cocoa farms. Adoption of good agronomic practices is crucial for the sustainability of cocoa cultivation and this chapter describes good practice at both the pre- and post-planting stages. The chapter focuses on the challenge of rehabilitating cocoa farms, and includes a detailed case study on rehabilitation of farms in Ghana.

The final chapter of the section, Chapter 9, looks specially at the challenge of improving soil and nutrient management in cacao cultivation. The chapter summarises key research on the role and availability of key nutrients affecting cacao growth and health such as phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The variability of yield responses to nutrients has highlighted the ways these nutrients interact both with each other and other factors such as soil, climate, and topography. The chapter outlines a targeted approach to nutrition management based on correcting the soil so that the cacao can find the nutrients it needs in optimal quantities. Through two detailed case studies, the chapter discusses ways of determining an appropriate fertiliser formula for individual plots using physical-chemical analyses of soil samples.

Part 3 Diseases and pests

The third part of the volume summaries the latest research on understanding and combatting the major fungal and viral diseases affecting cocoa. The subject of Chapter 10 is the cocoa disease witches' broom. Caused by the hemibiotrophic basidiomycete *Moniliophthora perniciosa*, witches' broom is one of the most serious cocoa diseases. The pathogen co-evolved with cocoa in the Amazon River basin and is currently restricted to South and Central America but represents a serious risk to other cocoa-producing regions of the world are at risk. In the last few years new technologies such as bioinformatics and the establishment of a robust model of host-plant interaction have enabled significant advances in our knowledge of witches' broom. The chapter reviews the latest research on disease physiology, genomics and transcriptomics, diversity, and management practices to control the disease.

Moving on to another major cocoa disease, Chapter 11 focuses on frosty pod rot, caused by the fungus *Moniliophthora roreri*. The chapter summarises what we know about the pathogen before considering the spread, invasion risk and impact of *moniliophthora roreri* on cocoa. The chapter then examines management options for dealing with the disease, including ways of preventing and minimizing the impact of invasive species which spread disease.

Continuing the theme of cocoa diseases, Chapter 12 looks at vascular-streak dieback (VSD), caused by a previously undescribed tullasneloid basidiomycete, *Oncobasidium theobromae* (now *Ceratobasidium theobromae*). The chapter describes the symptoms of VSD and the biology of the pathogen, the disease's epidemiology and methods of management, as well as including a detailed case study showing the importance of field studies in identifying, tracking and preventing the disease.

Moving away from the subject of diseases, Chapter 13 considers insect pests affecting cacao. Pests have a major impact on cacao production, both from direct damage to crops and as vectors of disease. Estimates of losses due to pest and disease range from 30– 40%. The use of pesticides for pest control can have numerous negative impacts on the environment and human health. An integrated and holistic approach is therefore required to enhance and sustain crop production. The chapter describes the main insect pests attacking cacao in each of the three principal production regions: the Americas, Africa and Asia, and outlines control measures adopted for each of the main insect pests. The chapter also includes detailed case studies that showcase how research can help to develop more sustainable and environmentally-friendly control measures.

The focus of Chapter 14 is on nematode pests of cocoa. Plant-parasitic nematodes cause significant cocoa yield losses, sudden death of trees and retardation of seedling growth in nurseries. The chapter explores the challenges in identifying damage caused by nematodes. It then describes the main nematode pests associated with cocoa and typical damage symptoms. The chapter also addresses available control options in successful nematode management.

The final chapter of the section, Chapter 15, turns to advances in pest and disease-resistant cocoa varieties. Cocoa production is increasingly subject to parasitic pressures. Currently, Cacao Swollen Shoot Virus (CSSV) threatens the production of the largest production basin in West Africa, in Côte d'Ivoire, Ghana, Togo and Nigeria. In Asia, Cocoa Pod Borer and Vascular Streak Dieback (VSD) hamper the extension of cultivation areas and reduce production. In South America, where cocoa originated, Moniliasis and Witches Broom have significantly limited production. Other pests, like mirids or black pod disease due to several species of *Phytophthora*, also affect cacao production. The chapter describes the genetic improvement of resistance, focusing on the widely prevalent black pod disease. The chapter discusses the use of new tools coming from molecular biology, including marker assisted selection (MAS) and genomic selection (GS), and the ways they are being used in breeding for *Phytophthora* disease resistance.

Part 4 Safety and sensory quality

The fourth part of the volume covers safety and quality issues. Echoing themes in Chapter 13, the subject of Chapter 16 is improving best practice with regard to pesticide use in cocoa. Consumer concerns about food safety have been translated into regulations governing minimum pesticide residues in cocoa. Consequently, development and implementation of best practice for pesticide use is critical, but presents major challenges. The chapter includes detailed case studies on establishing baselines, effective monitoring promoting awareness and developing a holistic approach.

Moving from the danger of pesticide traces to toxins left behind by fungi, Chapter 17 considers the causes, detection and control of mycotoxins in cocoa. Mycotoxins are produced as secondary metabolites by various species of filamentous fungi, and may affect many agricultural crops and products. The potential health risks associated with these chemical compounds mean that significant attention has been given to their detection and control. However, most study has so far been dedicated to mycotoxin contamination of agricultural crops such as cereals, with less attention given to cocoa. The chapter presents an overview of the current understanding of mycotoxin contamination of cocoa. The main groups of mycotoxins are discussed, followed by a summary of three methods of detection. The chapter then explains the various methods of controlling mycotoxins in cocoa and discusses attempts to decontaminate infected crops. The chapter concludes that there is a need for more research into the different mycotoxins affecting cocoa and methods of reducing their presence and impact.

The final chapter of the section, Chapter 18, focuses on analysing sensory and processing quality of cocoa. Flavour is a critical aspect of cocoa quality, determining to a large extent the value and end use of traded cocoa beans. The chapter provides a road map towards bridging the knowledge gap that currently exists between industry and cocoa producers by defining approaches for analysing the sensory and processing quality of cocoa. The

chapter describes the development of more practical and harmonized quality criteria for cocoa farmers around the world. It also explores research on the genetic expression of flavor, developments in sensory evaluation and the use of both physical and sensory evaluation as a tool to drive improvements in the cocoa value chain.

Part 5 Sustainability

The final part of the book looks at ways of improving the environmental sustainability of cocoa production. The subject of Chapter 19 is the relationship between climate change and cocoa cultivation. The chapter provides a number of case studies which focus on global climate projections for cocoa producing regions, including assessment of regionally-differentiated climate change impacts in Côte d'Ivoire.

Keeping with the theme of the interaction between cocoa production and the environment, Chapter 20 considers critical issues in applying agroforestry science to cocoa cultivation programmes. Cocoa-based agroforestry systems are a conspicuous element of agricultural landscapes worldwide. The chapter concentrates on the analysis and design of the shade canopy in cocoa-based agroforestry systems. Shade canopy analysis and design is a key component of crop husbandry, and requires a good understanding of the interactions, synergies and trade-offs between shade, yield and environmental services. The chapter provides a robust approach to analyze and design an optimal shade canopy that provides a diverse, resilient system which balances differing requirements such as carbon storage and cocoa yields.

Chapter 21 provides an overview of methods for organic cocoa cultivation. As a crop, cocoa can be grown successfully using organic methods, and demand for organic chocolate has risen in line with the overall growth in the organic market. The chapter offers a summary of current issues in the production of organic cocoa. The chapter also considers issues surrounding the certification and pricing of organic cocoa. The chapter summarises a variety of different cultivation methods, such as the differences between agroforestry-based cultivation and full-sun grown cocoa cultivation. Finally, the chapter considers different techniques for controlling pests and diseases without the use of chemical inputs.

Complementing the preceding chapters, Chapter 22 considers cocoa sustainability initiatives. Largely implemented by cocoa farmers and groups, sustainability initiatives are often supported by traders, government agencies, certification organisations and other not-for-profit organisations. The chapter examines the different sustainability initiatives and their social, economic and environmental impacts on cocoa farmers, cocoa farms and cocoa ecosystems. The chapter provides detailed case studies of impacts in Ghana and Côte d'Ivoire.

The volume's final chapter, Chapter 23, looks at supporting smallholders in achieving more sustainable cocoa cultivation. The chapter examines the recent evolution of sustainability in the cocoa and chocolate value chain. Using the case of West Africa, especially the countries of Côte d'Ivoire and Ghana, the chapter examines the key social, economic, and environmental challenges facing smallholders. The chapter provides an overview of initiatives undertaken by public and private actors to address these problems. The chapter focuses on collaborative efforts that bring together various private sector actors in the value chain. The chapter concludes by considering three important developments in the areas of voluntary certification and standards; the discussion of a living income; and the question of price and future supply and demand for cocoa.

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