BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Achieving sustainable cultivation of coffee

Breeding and quality traits

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SCIENCE PUBLISHING

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Introduction

Coffee is one of the most widely traded commodities in the world, with *Coffea arabica* and *C. canephora* together accounting for 99% of the global coffee bean production. Despite its popularity as a beverage and its economic importance, sustainable coffee production currently faces a number of challenges. This is primarily due to an over reliance on a relatively small number of varieties vulnerable to a range of abiotic and biotic stresses, as well as the increasing expectations of quality amongst consumers. These challenges are addressed in *Achieving sustainable cultivation of coffee*.

Part 1 focuses on advances in understanding plant physiology and ensuring genetic diversity. These advances provide the basis for chapters summarizing developments in breeding improved varieties of Arabica and Robusta coffee. Part 2 reviews our understanding of the chemical composition, sensory properties and the potential nutraceutical benefits of coffee. Chapters also look at wider quality and sustainability issues.

Part 1 Plant physiology and breeding

Chapter 1 reviews the diversity of coffee and the evolution of its genome. While the worldwide production of coffee relies on a small number of cultivars, wild coffee trees represent huge reserves of genetic diversity that could help to mitigate the effects of an unstable climate and plant diseases, as well as improve health-related chemicals present in coffee seeds. This chapter describes the results of studies of coffee tree species distribution and characterization, reproduction biology, genome organization and evolution, phylogenetic relationships among coffee species and the molecular bases of coffee species diversification, as well as looking ahead to future developments in this area.

In Chapter 2, some aspects of coffee growth and development as well as the recent advances in the environmental physiology of growth and production are reviewed. The information deals with both *Coffea arabica* and *C. canephora*. This chapter is organized into sections dealing with vegetative growth, flowering and fruiting, competition between vegetative and reproductive growth, and physiological acclimation to environmental factors such as light, water and temperature.

Chapter 3 focuses on how the reserve compounds that accumulate in coffee seeds contribute – directly or via roasting-induced chemical reactions – to the broad spectrum of aromas and flavours in coffee. Coffee seed reserves are mainly composed of cell wall polysaccharides, lipids, proteins, sucrose and secondary metabolites including chlorogenic acids, caffeine and trigonelline. Understanding coffee quality requires a detailed characterization of the metabolic pathways in the synthesis of these aroma/flavour precursors. This chapter describes the current state of knowledge on the relationships between coffee quality, seed chemical composition and genetic and environmental effects, with a special focus on environmental regulation of coffee seed metabolic pathways. It includes a case study of coffee production on La Reunion Island and provides suggestions for further reading, as well as looking ahead to future developments in coffee seed chemical composition research.

As Chapter 4 points out, utilizing the varied genetic resources of coffee to develop varieties with drought stress tolerance, pest and disease resistance, high cup quality and increased yields will ensure the future sustainability of the crop. This chapter examines

the genetic resources of coffee in both *ex situ* collections and *in situ* situations. It also provides a detailed case study of the conservation of one coffee variety in Madagascar in the context of the development of the Global Strategy for the Conservation for Coffee Genetic Resources, and looks ahead to future developments in this area.

Chapter 5 focuses on the fact approximately 60% of the annual world coffee production is harvested from Arabica (*Coffea arabica*), with the remainder harvested from Robusta (*C. canephora*) coffees. The former is superior in beverage quality, but more expensive to cultivate. The demand for quality coffees is steadily increasing, but anticipated climate change may jeopardize the sustainability of Arabica coffee production. This chapter reviews the achievements of several coffee research centres in conserving and evaluating genetic resources and variety development in Arabica coffee, and discusses the main preconditions for successful next-generation variety development. These are related to genetic variation, disease and pest resistances, tolerance to abiotic stress factors, beverage quality and cost-effective mass propagation of hybrid cultivars. Breeders will have to combine classic selection methods with advanced genetic and genomic technologies in order to meet the challenge of developing resilient (hybrid) cultivars for sustainable, climate-change tolerant Arabica coffee production.

Chapter 6 builds on Chapter 5 by focusing on Robusta coffee. As the chapter points out, the two species differ from each other in their centre of origin, breeding behaviour, growth habit, adaptability, production potential and quality attributes but together produce unique blends for the consumer. This chapter offers a comprehensive review of key issues in the development of Robusta coffee varieties, including genetic resources, breeding behavior, growth and agronomic requirements. This chapter describes the genetic structure of Robusta base populations and their phenotypic variability and initiatives to develop improved varieties. Building on both Chapters 5 and 6, Chapter 7 argues that faster breeding methods are needed for coffee to be able to cope with the challenges of climate change that lie ahead. This chapter focuses on molecular breeding techniques for *Coffea canephora* (Robusta coffee). The chapter examines genetic diversity, the development of molecular markers and the current state of molecular breeding, as well as looking ahead to future developments in this area.

Chapter 8 focuses on the fact that regular Arabica coffee contains approximately 1.2% caffeine. 'Decaffeinated' (less than 0.1%) and 'low-caffeine' (0.2–0.8%) coffee can be obtained by removing the caffeine. However, this can compromise the flavour and may lead to consumers viewing the product as less 'natural'. Over the past 25 years, considerable effort has been made on developing naturally non- or low-caffeinated varieties, and some coffee beans with reduced caffeine content are now commercially available. Chapter 8 first reviews the process of caffeine biosynthesis and the economic significance of naturally decaffeinated and low-caffeine coffee. The chapter considers the varying levels of caffeine in different coffee species, the production and characteristics of non- and low-caffeine coffee, and the challenges of moving to large-scale cultivation of new varieties.

Chapter 9 points out that, although coffee is one of the most valuable agricultural commodities of the world, it is an orphan crop in relation to investment in plant breeding. An efficient system to develop, introduce and propagate improved coffee varieties is required to place productive and affordable plants at farmers' disposal. This chapter describes ways of developing and propagating new coffee varieties to increase the efficiency of coffee production without compromising end-product quality. The chapter considers the physiological constraints of coffee variety development, the legal aspects of plant or seed shipments, and the protection of the breeder's rights within national or

international systems. This chapter also discusses multilocation trials, and discusses trends for the future and recent initiatives that may be able to accelerate the development and deployment of genetic innovation at the farmer level.

Part 2 Quality traits

Chapter 10 provides an overview of what we know about the composition of green coffee beans and the changes associated with roasting and beverage production. It provides a context for the following chapters. The chapter reviews recent advances related to the major chemical components of coffee such as the chlorogenic acids, the alkaloids (caffeine and trigonelline), the diterpenes (cafestol and kahweol), volatile aromatics and the melanoidins.

Chapter 11 focuses on the fact that in recent years, the health benefits of coffee beverage consumption have attracted considerable interest. This chapter describes the latest research on the potential health benefits of coffee components including caffeine, phenolics, trigonelline, cafestol and kahweol. The chapter pays particular attention to the antioxidant, anti-inflammatory and antimicrobial properties of these compounds, and evaluates the results of clinical studies of the effects of coffee beverage consumption on human health.

Chapter 12 explores an underutilized component of the coffee plant, the leaves. The leaves of the coffee plant have a significant impact on fruit quality, and identifying markers in leaves for plant adaptability to environmental stress provide an indication of the quality of future fruits. This chapter provides an inventory of molecules identified to date in the leaves of cultivated coffee trees which are characterized by a high antioxidant potential. The chapter describes the beneficial effects of the molecules found in leaves on both plant physiology and human health, and suggests where future trends of research in this area may lead.

Chapter 13 builds on Chapter 11 by describing the growing number of studies demonstrating that coffee is a complex mixture of bioactive substances that may act together to help prevent disease when consumed in the correct way. This chapter reviews the literature on the nutritional and health-related aspects of regular coffee consumption, and examines the evidence on the beneficial health effects of coffee as well as potential side effects, and looks ahead to future research in this area.

Chapter 14 discusses how coffee's global appeal is related to its unique flavour, taste and mouthfeel. Coffee is the second most traded global commodity after petroleum, and a thorough understanding of the chemical dynamics associated with its aroma is essential to its popularity. This chapter covers the chemical composition of green coffee beans, the process of roasting, the profile of volatile and non-volatile compounds generated by roasting, and the chemical reactions responsible for their formation. The chapter discusses topics such as the presence of incidental compounds in roasted coffee and the key volatiles in the determination of coffee aroma.

Chapter 15 focuses on the fact that in recent years, public health issues in the food industry have led to regulations concerning contaminants in foodstuffs, including coffee. Four main types of compound are known to contaminate coffee, starting with pesticides that come from agricultural treatments, transport and storage. Ochratoxin A is the main mycotoxin found in coffee and is linked to environmental conditions and postharvest

processing. Polycyclic aromatic hydrocarbon contamination can be of exogenous (during drying) or endogenous (during roasting) origin, and finally, acrylamide appears during roasting. This chapter discusses each of these compounds, reviewing our current state of knowledge, regulations for avoiding or dealing with contamination, and effective ways of limiting contamination.

Chapter 16 focuses on quality which, in the case of coffee, ultimately means flavour. The assessment of coffee flavour quality is therefore the key tool for the quality assurance of coffee, and is essential in strategies for achieving higher value coffee. The chapter discusses the definition of 'quality' and reviews the many interesting advances in the prediction of coffee flavour using instrumental, analytical methods. It highlights the continued importance of sensory assessment in analysis of coffee flavour. This usually means cupping, the process of grading coffee quality based on tasting performed by an expert using a specific protocol. The chapter reviews how cupping has evolved, the protocols involved and how it can be used as a tool to reach consensus regarding quality. The chapter also considers other important quality parameters related to coffee processing.

Chapter 17 discusses detection of the fraudulent adulteration of coffee. Both coffee manufacturers and legislative authorities are responsible for establishing quality standards through labelling, composition regulations and routine evaluation protocols to circumvent unfair competition among manufacturers, as well as to ensure the safety, quality and authenticity of the product for consumers. This chapter addresses current issues in the area of adulteration of coffee as well as describing recent progress on coffee quality evaluation and authentication using metabolomics. The chapter includes a detailed case study on the application of GC/MS and GC/FID-based metabolomics to authenticate Asian palm civet coffee, and looks ahead to future research trends in this area.

Chapter 18 presents the concepts and tools around life cycle assessment (LCA) and carbon footprint (CFP) analysis and their applications to the coffee value chain. Coffee is characterized by a particularly complex value chain with multiple actors involved along every step from production to the consumer. This chapter explains the concepts of life cycle analysis and describes in detail how carbon footprint analysis can be used to upgrade coffee value chains. The chapter includes a case study on the use of the EX-ACT value chain tool in Haiti.

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