BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Global tea science

Current status and future needs

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Introduction

Tea is the most widely-consumed beverage in the world. Like other crops, tea cultivation faces a number of challenges. With the challenge of climate change and the competition for scarce resources, there is a need to make tea cultivation more efficient and sustainable. Cultivation of tea also needs to be more resilient to biotic and abiotic stresses, whether it be pests or more extreme weather (e.g. drought) associated with global warming.

Fortunately, there is a range of research addressing these challenges. Drawing on international expertise, this volume summarises global tea science by focusing on ways of improving the cultivation of tea at each step in the value chain, from breeding through to harvest. The volume emphasises the importance of interdisciplinary and collaborative research and summarises the key research trends in each area, putting them in the context of tea cultivation as a whole. It reviews the latest advances in understanding tea genetics and genetic diversity and how this has informed advances in conventional, marker-assisted and transgenic breeding techniques. Likewise, the volume summarises current best practices in cultivation techniques and control of pests and diseases, focusing on assessment of the environmental impact of tea cultivation.

Part 1 Tea Breeding and Germplasm

Part 1 reviews advances in tea breeding and issues concerning tea germplasm. The focus of Chapter 1 is on ensuring the genetic diversity of tea. Prolonged cross-pollination within and between populations of tea plants and related species in the 'wild' have produced considerable heritable variation, resulting in a high level of genetic diversity. A good understanding and management of this pool of genetic resource diversity is of vital importance to tea plant improvement, since it directly affects the potential for genetic gain through selection. The chapter provides an overview of the genetic diversity of the tea plant and its characterization and utilization. The chapter examines the origin and global distribution of tea cultivars, assessing the current status of tea genetic resources. The chapter explains the processes of tea germplasm evaluation and characterization and examines the exploitation and utilization of genetic diversity.

Developing the themes of Chapter 1, the focus of Chapter 2 is on mapping and exploiting the tea genome. As a dicotyledonous, perennial, evergreen and cross-pollinated woody plant, tea plant possesses a complex genetic background and high heterozygosity. Most of the genetic regulation information related to important traits is still unclear and many bottlenecks are hindering the mapping and exploiting of the tea genome. The chapter reviews progress in the construction of genetic linkage maps and the identification of qualitative trait loci (QTL) for the tea plant, as well as assessing the progress of functional genomics in exploiting genes associated with desirable traits. The chapter discusses the progress, challenges and potential advances in 'omics' for the tea plant.

Following on from Chapter 2's emphasis on mapping the tea genome, Chapter 3 moves on to address advances in genetic modification of tea. Due to its botanical characteristics, genetic improvement of tea is slow. Its high gestation period, the difficulty of producing homozygous lines, and the non-availability of mutant genotypes and a mapping population are all hindrances to development. The chapter describes and evaluates the potential of genetic transformation as an alternative for varietal improvement of tea, via

the deployment of *agrobacterium* and particle bombardment. The chapter describes in detail progress global progress on research into transgenic tea.

Part 2 Cultivation and Agronomy

The second part of the volume discusses agronomics of tea plant and improvements in tea cultivation techniques. Chapter 4 examines the planting and cultivation of tea. Originating in natural forests characterized by warm and humid environmental conditions and nutrient rich soils, tea's growth and yield largely depend on climatic and soil factors. Frequent removal of photosynthetically-active shoots (harvesting), and periodic removal of leaf-bearing branches (pruning), exert physiological stress on the bush, and it is crucial for sustainable productivity and profitability that the tea bush is provided with optimum conditions for normal growth. The chapter examines in detail the process of new planting, soil rehabilitation and re-planting, aftercare, field operations such as pruning, establishing shade trees and wind belts and harvesting. The chapter looks ahead to future trends, challenges and potential developments in this area.

Moving from Chapter 4's overview of tea planting, Chapter 5 focuses on the contribution of agronomic cultivation techniques to improving tea quality. The profitability of tea production depends on whether the type of tea produced has the right quality that is acceptable to consumers. This chapter examines the environmental and agronomic factors underlying tea quality, addressing the chemical quality parameters of tea, the relationship between black tea quality and specific cultivars, the effect of environmental factors such as altitude and temperatures and the relationship between tea quality and agronomic inputs.

Chapter 6 examines the potential role of arbuscular mycorrhizal fungi (AMF) in tea cultivation. Continuous application of chemical fertilizers in tea gardens may increase tea production, but it adversely affects the quality of tea soils. There is therefore growing interest in rhizosphere associates of tea, including symbionts such as arbuscular mycorrhizal fungi (AMF). These colonize tea roots and support both plant growth and improvement of soil health. The chapter reviews the use of AMF-based bio-inoculants in tea cultivation, examining the range of AMF associated with tea and their effects on tea rhizosphere. The chapter considers the development of an AMF-based bioformulation for use in tea plantations and reviews the effects of using such a bioformulation on both tea plant growth and tea quality.

Chapter 7 focuses on the role of tea soil microflora in enhancing tea cultivation. Tea crops can suffer from nutrient deficiencies, attack by diverse pests and pathogens, and climatic stresses, which result in considerable crop losses. However, the application of synthetic chemicals to alleviate crop loss has had a detrimental impact on the tea ecosystem. Plant growth-promoting microorganisms (PGPMs) play an essential role in the maintenance of sustainable tea cultivation and ecosystem restoration, thereby promoting primary productivity and inducing systemic resistance of plants to diverse pests and diseases. The chapter summarizes and discusses recent progress regarding the understanding of tea soil microflora and its significance to tea plantations. It provides an overview of soil microbial inoculants as biofertilizers, as well as describing nitrogen-fixing, phosphate-solubilizing, potash-solubilizing and cellulose-degrading microbial biofertilizers. The chapter concludes that selection of microbial bioagents might form a reliable component in the management of significant tea diseases in order to achieve sustainable tea production.

Part 3 Plant Protection

The focus of the third part of the volume is on the protection of tea plants. Chapter 8 reviews diseases affecting tea plants. These include foliar diseases, stem diseases and root diseases. The chapter examines developments in disease resistance, including resistance of fungi to fungicides and the creation of disease-resistant tea plants. The chapter reviews recent advances in the management of tea diseases and advances in the molecular biology of tea diseases that may assist in increasing resistance.

Chapter 9 examines the impact of insect pests of tea. The tea plant is a perennial crop and every part of the plant is prone to infestation by some pests over its lifetime. The prevalence and occurrence of a pest is primarily determined by the specific agro-climatic conditions, the type of cultivar and the cultural practices adopted within a given specific location. The chapter describes the biology and ecology of important pests attacking tea in different tea growing areas of the world and the type of damage/injury induced, focusing on shot-hole borers, termites (both live wood and scavenging varieties) and nematodes.

Chapter 10 continues the focus on insect pests of tea, this time considering the impact of caterpillars and other seasonal pests, as well as sucking pests and occasional and minor pests. This class of pests causes damage to tea plants largely through feeding. The chapter considers a variety of factors associated with each of these pests, including their geographical distribution, appearance, the damage caused and their respective biology and ecology. The chapter looks ahead to future research into these pests, including understanding their behavior and habitats, their sensitivity to temperature, humidity and climate change in general.

Bringing together the themes of Chapters 9 and 10, the Chapter 11 considers the challenge of integrated pest management (IPM) of tea insect pests. The chapter describes the various strategies that are being used in different countries to manage pests of tea using integrated pest management programme (IPM) to ensure they do not reach economic injury levels. The chapter explores pest detection methods as well as methods of mechanical, biological, cultural and chemical control of insect and nematode pests of tea, and includes a number of detailed case studies describing the application of these methods in IPM.

Chapter 12 moves on to the problem of pesticides, addressing the measurement and reduction of pesticide residues in tea. Tea growers require pesticides to prevent crop loss due to pest attacks, which are aggravated by climate change. Since pesticides invariably leave residues, it is of the utmost importance that samples of traded tea are monitored to ensure compliance with food safety standards. The chapter reviews research into the extent of pesticide residues in tea, conventional methods for determining trace levels of multiple residues in tea and the problems with these methods, as well as advanced, rapid methods which are more suitable for ensuring food safety. The chapter also considers food safety standards in the EU and Japan, the challenge of maintaining maximum residue limits (MRLs) and methods of assessing the risk posed by pesticide residues, and strategies for reducing the residues in tea.

Part 4 Tea Chemistry and Phytochemicals

The focus of the fourth part of the volume is on the chemistry of tea and the role of phytochemicals. Chapter 13 examines qualitative and quantitative analysis of the

phytochemical composition of tea. Tea contains many phytochemicals that demonstrate important physiological properties and health promoting benefits, such as polyphenols, amino acids, vitamins, carbohydrates, and purine alkaloids. Tea components are closely associated with tea variety, the growing conditions and regions of tea plants, and the plucking and processing of tea leaves. The chapter reviews the main chemical components in tea and the instrumental techniques to identify them. The chapter describes phytochemical bioactive compounds as well as flavour and colour compounds, before going on to consider analytical techniques for tea characterization, including chromatic, spectroscopic techniques. The chapter then examines the determination of phenolic compounds and sugars, volatile compounds and other compounds and elements.

Chapter 14 moves from the chemical analysis of compounds in tea to consider the potential beneficial effects of these compounds, specifically the role of tea in combating chronic diseases. The chapter considers the chemical properties, bioavailability and biotransformation of the constituent elements of tea, and assesses the connection between tea consumption and cancer prevention. The chapter considers the impact of tea on reduction of body weight, leading to alleviation of metabolic syndrome and preventing diabetes. It also considers claims that tea can lower blood cholesterol, blood pressure and incidence of cardiovascular diseases. Finally, the chapter considers potential neuroprotective effects of tea.

Part 5 Sustainability

The fifth part of the volume considers the challenge of making tea production sustainable. Chapter 15 considers the relationship between climate change and tea cultivation. Predicted climate change is likely to pose a major threat to normal tea cultivation. This chapter reviews the effects that climate change is likely to have on regions suitable for tea production and the duration of the plucking period. The chapter considers how tea production might be improved by temperature increases and CO_2 elevation; it also discusses the negative impact of heavy rains, frosts, proliferation of pests and diseases and soil degradation. The chapter concludes that tea quality is likely to deteriorate due to the imbalance in the ratio of free amino acids to polyphenols. Appropriate planning for adaptation and mitigation needs to be developed and extended for sustainable development of the tea industry. The adaptation and mitigation strategies should operate at three levels: government policy, research and development for new technologies and techniques and community involvement and technology extension.

Complementing the preceding chapter's focus on climate change and its impact on tea quality, Chapter 16 assesses the environmental impact of tea cultivation itself and prospects for reducing these impacts. Owing to its popularity, tea has become an important plantation crop in many countries. As a perennial crop occupying a large proportion of arable land, assessing its environmental impact would benefit the economy of tea growing countries immensely. This chapter reviews the impact of the tea industry on the environment and human activity. It covers life cycle assessment methodologies tailored to tea production, covering cultivation to final waste disposal, tea's carbon footprint as well as other on and off-farm impacts caused by the tea industry. Further possible measures to minimize these impacts are also discussed. Two detailed case studies address the CO_2 sink/source nature of tea plantations as the cultivation stage is one of the most significant contributors to the carbon footprint of tea.

Chapter 17 moves on to consider the cultivation and marketing of organic tea. The chapter provides an overview of the development of organic and biodynamic tea production in different producing countries, exploring cultivation practices, the global market for and trade in organic tea, and research priorities. The chapter assesses the pattern of yield trend after conversion from conventional to organic production, providing a discussion of the development of target markets for organic tea, distribution channels and the volume of organic tea traded in the world market. The chapter examines the challenges of establishing and maintaining a new organic tea plantation, as well as the maintenance of new and converted organic plantations. It addresses post-harvest and manufacturing practices, inspection and certification of organic tea and the future prospects for organic tea cultivation. The chapter provides an overview of the major producing countries of organic tea and the major markets for this product.

Continuing the theme of sustainable forms of tea cultivation, the final chapter in the book, Chapter 18, considers the importance of supporting smallholders producing tea. The chapter describes how smallholder organization can be strengthened to support tea cultivation. Smallholders are weak in terms of productivity owing to low yields and lack of working capital in comparison with large state-owned and private plantations. The chapter describes how the transition from a smallholders' group to a smallholder-owned company can be managed, and reviews existing literature on smallholder development and lessons that can be learned in this area. Finally, it examines the ways in which smallholder-owned companies compete and form partnerships.

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