

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Global tea science

Current status and future needs

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SCIENCE PUBLISHING

Contents

Series list	xi
Acknowledgements	xv
Introduction	xvi

Part 1 Tea Breeding and Germplasm

1	Ensuring the genetic diversity of tea plants	3
	<i>Jian-Qiang Ma and Liang Chen, Tea Research Institute of the Chinese Academy of Agricultural Sciences (TRI, CAAS), China</i>	
	1 Introduction	3
	2 Origins and distribution of tea	4
	3 Status of tea genetic resources	4
	4 Germplasm evaluation and characterization	8
	5 Exploitation and utilization of genetic diversity	10
	6 Future trends and conclusion	13
	7 Where to look for further information	14
	8 References	15
2	Mapping and exploiting the tea genome	21
	<i>Xinchao Wang, Xinyuan Hao, Lu Wang and Yajun Yang, Tea Research Institute of the Chinese Academy of Agricultural Sciences (TRI, CAAS), China</i>	
	1 Introduction	21
	2 Progress in genetic linkage map construction and qualitative trait locus (QTL) identification for the tea plant	22
	3 The progress of functional genomics in exploiting genes associated with desirable traits	24
	4 Progress in 'omics' research: overview and secondary metabolites	25
	5 Progress in 'omics' research: stress response and dormancy	27
	6 Conclusion and outlook	29
	7 Where to look for further information	30
	8 Acknowledgements	31
	9 References	31
3	Advances in genetic modification of tea	37
	<i>Mainaak Mukhopadhyay, University of Kalyani, India; and Tapan Kumar Mondal, National Bureau of Plant Genetic Resources, India</i>	
	1 Introduction	37
	2 Conventional tea propagation	37
	3 The need for genetic transformation	38
	4 Transformation systems	39
	5 Methods of transformation	40
	6 Conclusion and future trends	47
	7 Where to look for further information	48
	8 References	48

Part 2 Cultivation and Agronomy

4	Planting and cultivation of tea	53
	<i>M. A. Wijeratne, Tea Research Institute, Sri Lanka</i>	
	1 Introduction	53
	2 Climatic requirements of tea	54
	3 New planting of tea	55
	4 Preparation of the planting hole	59
	5 Planting of tea	61
	6 Aftercare field operations	61
	7 Establishment of shade trees and wind belts	65
	8 Pruning	67
	9 Harvesting of tea	72
	10 Replanting	79
	11 Soil rehabilitation	80
	12 Future trends and conclusion	81
	13 Where to look for further information	81
	14 References	82
5	The effect of cultivation techniques on tea quality	85
	<i>P. Okinda Owuor, Maseno University, Kenya</i>	
	1 Introduction	85
	2 Chemical quality parameters of tea	86
	3 Cultivars and black tea quality	88
	4 Environmental factors	91
	5 Altitude and temperatures	93
	6 Agronomic inputs and tea quality	95
	7 Conclusion	102
	8 Where to look for further information	102
	9 Acknowledgement	102
	10 References	102
6	The role of arbuscular mycorrhizal fungi in tea cultivation	113
	<i>Shipra Singh and Anita Pandey, G. B. Pant National Institute of Himalayan Environment and Sustainable Development, India; and Lok Man S. Palni, Graphic Era University, India</i>	
	1 Introduction	113
	2 AMF, tea and the tea rhizosphere	115
	3 Development of AMF-based bioformulation for tea plantations	120
	4 Plant growth promotion following inoculation with AMF consortia	125
	5 AMF inoculation, tea growth and tea quality	126
	6 Conclusion and future perspectives	128
	7 Where to look for further information	130
	8 Acknowledgements	130
	9 References	130
7	The role of microbes in tea cultivation	135
	<i>P. N. Bhattacharyya and S. R. Sarmah, Tocklai Tea Research Institute, India</i>	
	1 Introduction	135
	2 Soil microbial inoculants as biofertilizers: an overview	137

3 Nitrogen-fixing microbial biofertilizers	139
4 Phosphate-solubilizing, potash-solubilizing and cellulose-degrading microbial biofertilizers	141
5 Microbial management of pests and diseases in tea	144
6 Important interactions and mechanisms of action in the microbial management of disease	147
7 Tea pest management: microbiological approach	150
8 Selection and characterization of microbial products for commercialization	153
9 Conclusions, future prospects and challenges	155
10 Acknowledgements	157
11 References	157

Part 3 Plant Protection

8 Diseases affecting tea plants	171
<i>G. D. Sinniah, Tea Research Institute, Sri Lanka</i>	
1 Introduction	171
2 Foliar diseases affecting tea	172
3 Stem diseases affecting tea	178
4 Root diseases affecting tea	182
5 Development of resistance: resistance of fungi to fungicides and tea plants to diseases	186
6 Recent advances in the management of tea diseases	187
7 Advances in the molecular biology of tea diseases	189
8 Disease forecasting for tea	192
9 Conclusion	192
10 Future research needs	192
11 Where to look for further information	193
12 References	194
9 Insect pests of tea: shot hole borers, termites and nematodes	201
<i>Nalini C. Gnanapragasam, Former Deputy Director (Research), Tea Research Institute, Sri Lanka; currently Agricultural Tea Consultant - Malwatte Valley Plantations PLC, Sri Lanka</i>	
1 Introduction	201
2 Shot hole borers	206
3 Termites of tea: general comments	213
4 Live wood termites	213
5 Scavenging termites	219
6 Nematodes	222
7 Where to look for further information	231
8 Acknowledgements	232
9 References	232
10 Insect pests of tea: caterpillars and other seasonal, occasional and minor pests	241
<i>Nalini C. Gnanapragasam, Former Deputy Director (Research), Tea Research Institute, Sri Lanka; currently Agricultural Tea Consultant - Malwatte Valley Plantations PLC, Sri Lanka</i>	
1 Introduction	241
2 Caterpillars and other seasonal pests	242

3	Sucking pests	260
4	Occasional and minor pests	277
5	Conclusion	289
6	Acknowledgements	290
7	References	291
11	Integrated pest management of insect, nematode and mite pests of tea <i>Nalini C. Gnanapragasam, Former Deputy Director (Research), Tea Research Institute, Sri Lanka; currently Agricultural Tea Consultant - Malwatte Valley Plantations PLC, Sri Lanka</i>	301
1	Introduction	301
2	Detection methods	303
3	Mechanical control	305
4	Cultural control: cultivars and planting other crops	305
5	Cultural control: soil, bush sanitation, nutrient management and escape strategy	308
6	Biological control: botanicals and semiochemicals	310
7	Biological control: predators, bacteria and viruses	313
8	Chemical control	316
9	IPM programmes on selected perennial pests	325
10	Conclusion and future trends	328
11	Acknowledgements	330
12	References	330
12	Pesticide residues in tea: challenges in detection and control <i>A. K. Barooah, Tocklai Tea Research Institute, India</i>	347
1	Introduction	347
2	Measuring pesticide residues in tea	348
3	Review of recent research on the extent of pesticide residues in tea	349
4	Conventional methods for detecting residues in tea	352
5	Advanced methods for detecting residues in tea	354
6	Food safety standards for tea and the challenges of maintaining maximum residue limits (MRLs)	357
7	Strategies for reducing pesticide residues in tea	365
8	Conclusion and future trends	366
9	References	367

Part 4 Tea Chemistry and Phytochemicals

13	Instrumentation and methodology for the quantification of phytochemicals in tea <i>Ting Zhang, China University of Geosciences and Huanggang Normal University, China; Xiaojian Lv, Yin Xu, Lanying Xu and Tao Long, Huanggang Normal University, China; Chi-Tang Ho, Rutgers University, USA; and Shiming Li, Huanggang Normal University, China and Rutgers University, USA</i>	375
1	Introduction	375
2	Phytochemicals in tea: bioactive compounds	382
3	Phytochemicals in tea: flavour and colour compounds	388

4	Analytical techniques for tea characterization: overview and chromatic techniques	390
5	Analytical techniques for tea characterization: spectroscopic techniques	393
6	Determination of compounds in tea: phenolic compounds and sugars	395
7	Determination of compounds in tea: analysis of volatile compounds	400
8	Determination of compounds in tea: other compounds and elements	404
9	Diversified tea products	407
10	Summary	408
11	References	412
14	The potential role for tea in combating chronic diseases <i>Chung S. Yang, Rutgers University, USA</i>	427
1	Introduction	427
2	Chemical properties, bioavailability and biotransformation of tea constituents	428
3	Tea and cancer prevention	431
4	Reduction of body weight, alleviation of metabolic syndrome and prevention of diabetes	434
5	Lowering of blood cholesterol, blood pressure and incidence of cardiovascular diseases	438
6	Neuroprotective effects of tea	439
7	Conclusion	441
8	Where to look for further information	443
9	Acknowledgements	443
10	References	443
Part 5 Sustainability		
15	Tea cultivation under changing climatic conditions <i>Wenyan Han, Xin Li, Peng Yan, Liping Zhang and Golam Jalal Ahammed, Tea Research Institute of the Chinese Academy of Agricultural Sciences (TRI, CAAS), China</i>	455
1	Introduction	455
2	Climate change and climatic variability	456
3	Effects of climate change on the suitability of tea planting areas and plucking duration	458
4	Effects of climate change on tea production	459
5	Effects of climate change on tea quality	463
6	Adaptation and mitigation strategies	464
7	Conclusion	469
8	Where to look for further information	469
9	Acknowledgements	470
10	References	470
16	Assessing and reducing the environmental impact of tea cultivation <i>Thushari Lakmini Wijeratne, Tea Research Institute, Sri Lanka</i>	473
1	Introduction	473
2	The environmental impact of tea cultivation	474
3	Making tea cultivation more sustainable	476

4	Case studies: carbon sequestration and production	478
5	Summary and future trends	480
6	Where to look for further information	481
7	References	481
17	Cultivation, production and marketing of organic tea	485
	<i>Nikhil Ghosh Hajra, Organic Tea and Agri-horticultural Consulting, India</i>	
1	Introduction	485
2	Establishing and maintaining a new organic tea plantation	486
3	Maintenance of new and converted organic plantations	488
4	Post-harvest and manufacturing practices	503
5	Inspection and certification of organic tea	504
6	Future prospects for organic tea cultivation	505
7	Organic tea yield trends	506
8	Major producing countries of organic tea	507
9	Major markets for organic tea	510
10	Future trends and conclusion	515
11	Where to look for further information	515
12	Acknowledgements	516
13	References	516
18	Supporting smallholders in tea cultivation	521
	<i>Atik Dharmadi, Research Institute for Tea and Cinchona, Indonesia</i>	
1	Introduction	521
2	Smallholders and their role in tea cultivation	521
3	Problems facing smallholders	522
4	Disseminating good agricultural practices and improving market knowledge	523
5	Organizing smallholders to improve their position in the market	524
6	Case studies: Kenya and Sri Lanka	527
7	Conclusions	528
8	References	529
	Index	531

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 CO₂ 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 CO₂ 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.

Index

- Adsorptive column method 401
- Agrobacterium rhizogenes* 44–45
- Agrobacterium tumefaciens* 41–44
- Agronomic inputs
 - bioregulators 98
 - diseases 101–102
 - environmental pollution 101
 - foliar feeds and plant inoculants 98
 - and leaf handling 100
 - magnesium 97
 - nitrogen 96–97
 - organic fertilizers 97
 - phosphorous 97
 - plucking intervals 99–100
 - plucking standards 98–99
 - potash 97
 - pruning 101
 - shade 95
- Allomones 313
- AMF. see arbuscular mycorrhizal fungi (AMF)
- Arbuscular mycorrhizal fungi (AMF)
 - associations 115–120
 - based bioformulation
 - mass propagation 120–122
 - perennial host for 122–124
 - post-inoculum production 124–125
 - inoculation effect
 - benefits of 128
 - overview 126–127
 - overview 113–115
 - plant growth promotion
 - overview 125
 - phosphorus uptake 126
- Atomic emission spectroscopy (AES)/atomic absorption spectroscopy (AAS) 394
- Avian control 316
- BD. see biodynamic (BD) agriculture
- Beneficial health effects
 - bioavailability and
 - biotransformation 429–431
 - blood cholesterol/blood pressure/
cardiovascular diseases
 - possible mechanisms 439
 - studies in humans 438–439
 - cancer prevention
 - carcinogenesis in animal models 431–432
 - intervention studies 433
 - mechanistic considerations 433–434
 - observational epidemiological studies 432–433
 - neuroprotective effects 439–440
 - overview 427–428
 - overweight/obesity/type 2 diabetes
 - animal models 434–435
 - epidemiological studies 436
 - mechanistic considerations 436–438
 - randomized controlled trials 435–436
 - tea constituents and their properties 428–429
- Bioactive compounds
 - alkaloids 385, 405
 - amino acids 386, 404
 - carbohydrates 385–386
 - polyphenols 382–385
 - tea saponins 386–387, 405
- Biodynamic (BD) agriculture 493–496
- Biolistics 45–47
- Biological control
 - allomones 313
 - avian control 316
 - bacteria 316
 - botanicals 310–311
 - kairomones 313
 - other predators and parasites 314–315
 - pheromones 312
 - semiochemicals 312
 - spiders 314
 - synomones 312
 - viruses 315–316
- Blood cholesterol/blood pressure/cardiovascular diseases
 - possible mechanisms 439
 - studies in humans 438–439
- Botanicals 310–311, 498
- Brewed extraction 401
- Brew factor and risk assessment 364–365
- Bush sanitation 310
- Cancer prevention
 - carcinogenesis in animal models 431–432
 - intervention studies 433
 - mechanistic considerations 433–434
 - observational epidemiological studies 432–433
- Capillary electrophoresis (CE) 392
- Carbon sequestration and production 478–480
- Carotenoids 389–390
 - and chlorophyll 404
- Caterpillars
 - bunch caterpillar 253–255
 - looper caterpillar 247–250
 - oriental tea tortrix 246–247
 - smaller tea tortrix 245–246
 - tea leaf roller 252–253
 - tea tortrix 242–245
 - twig caterpillar 250–252
- CE. see capillary electrophoresis (CE)
- Cellulose-degrading microbial biofertilizers 144
- Chemical control
 - case studies 317–325
 - at physiological level 317

- Chlorophyll 389
 - and carotenoids 404
- Chromatographic techniques
 - capillary electrophoresis (CE) 392
 - gas chromatography (GC) 392–393
 - gas chromatography–mass spectrometry (GC–MS) 392–393
 - high-performance liquid chromatography (HPLC) 390–392
 - high-performance thin-layer chromatography (HPTLC) 393
 - liquid chromatography–mass spectrometry (LC–MS) 390–392
- Climate change, and tea cultivation
 - community involvement and technology extension 468–469
 - effects on tea production
 - CO₂ concentration 461
 - extreme climate events 462
 - modelling and temperature 460
 - pests and diseases 461–462
 - rainfall/monsoon 460–461
 - soil quality 462
 - solar radiation 462
 - effects on tea quality
 - CO₂ concentration 464
 - temperature and rainfall 463–464
 - environmental requirements for tea growth 458
 - extent of 456–457
 - extreme weather events 457–458
 - governmental policies and strategies 465–466
 - overview 455–456
 - research and development 466–468
 - shift of tea production areas 458–459
 - tea plucking duration 459
- CO₂ concentration
 - and tea production 461
 - and tea quality 464
- Colour compounds
 - carotenoids 389–390
 - chlorophyll 389
- Cultural control 498–500
 - avoiding planting alternate hosts 307
 - bush sanitation 310
 - escape strategy 310
 - grafting 306
 - growing antagonists 307
 - growing trap crops 307–308
 - host plant resistance 305–306
 - plant nutrients 309
 - soil amendments 309
 - soil condition 308–309
- Direct organic solvent extraction 400
- Diseases affecting tea
 - disease forecasting 192
 - foliar
 - bacterial shoot blight 177–178
 - blister blight 172–174
 - brown blight and anthracnose 175–176
 - effects of 178
 - grey blight 174–175
 - red rust 176–177
 - management of
 - biological control 187
 - botanicals 188
 - induced resistance 188
 - molecular biology of
 - identification and characterization of 189
 - molecular markers 191–192
 - molecular mechanisms 190–191
 - overview 171–172
 - resistance
 - description 186–187
 - fungicide 186
 - root
 - Armillaria* root rot 184–186
 - black root rot 184
 - brown root rot 183–184
 - charcoal root rot 184
 - red root rot 182–183
 - stem
 - cankers 178–180
 - wood rot 180–182
- Diversified tea products
 - instant tea 407–408
 - ready-to-drink tea 408
- Environmental factors
 - agronomic inputs
 - bioregulators 98
 - diseases 101–102
 - environmental pollution 101
 - foliar feeds and plant inoculants 98
 - and leaf handling 100
 - magnesium 97
 - nitrogen 96–97
 - organic fertilizers 97
 - phosphorous 97
 - plucking intervals 99–100
 - plucking standards 98–99
 - potash 97
 - pruning 101
 - shade 95
 - altitude and temperatures 93–95
 - carbon sequestration and production 478–480
 - chemical quality parameters 86–88
 - cultivars and black tea quality
 - parameters influencing 90–91
 - selection criteria 88–90
 - description 474–475
 - geographical location 93
 - overview 85–86, 473–474

- rainfall 94–95
- seasons/times of year 91–92
- sustainable making 476–478
- EU standards 358–360
- Euwallacea fornicatus* Eichhoff 325–326
- Flavour compounds
 - lipids 389
 - volatile compounds 388–389
- Foliar disease
 - bacterial shoot blight 177–178
 - blister blight 172–174
 - brown blight and anthracnose 175–176
 - effects of 178
 - grey blight 174–175
 - red rust 176–177
- Food safety standards
 - brew factor and risk assessment 364–365
 - EU standards 358–360
 - Japan's positive list system 360
 - MRL setting initiatives 360–364
- GAP. *see* good agricultural practices (GAP)
- Gas chromatography (GC) 392–393
- Gas chromatography-mass spectrometry (GC-MS) 392–393
- GC. *see* gas chromatography (GC)
- GC-MS. *see* gas chromatography-mass spectrometry (GC-MS)
- Genetic diversity
 - characterization of 8–10
 - complex phenotypes 13
 - core collection 12
 - cultivar improvement and protection 12–13
 - genetic resources
 - in Bangladesh 7
 - in China 5
 - in India 5
 - in Indonesia 7
 - in Japan 5–6
 - in Kenya 6
 - in Korea 6
 - in Sri Lanka 6
 - in Turkey 7–8
 - in Vietnam 6
 - germplasm evaluation 8
 - germplasm management 12
 - origin and domestication 11
 - origins and distribution of tea 4
 - overview 3–4
 - and taxonomy 10–11
- Genetic modification
 - conventional tea propagation 37–38
 - description 39–40
 - methods
 - Agrobacterium rhizogenes* 44–45
 - agrobacterium tumefaciens* 41–44
 - biolistics 45–47
 - overview 37
 - purpose of 38–39
- Glyptotermes dilatatus* Bugnion and Popof 326–327
- Good agricultural practices (GAP)
 - smallholders, in tea cultivation 523–524
- Grafting 306
- Harvesting, of tea
 - bearing and pruning 77
 - frequency of 75–76
 - generation 73–74
 - leaf handling 79
 - manual (selective) 74
 - mechanical 77–78
 - non-selective 77
 - severity of 75
 - standards of 76–77
- High-performance liquid chromatography (HPLC) 390–392
- High-performance thin-layer chromatography (HPTLC) 393
- Host plant resistance 305–306
- HPLC. *see* high-performance liquid chromatography (HPLC)
- HPTLC. *see* high-performance thin-layer chromatography (HPTLC)
- Infrared spectroscopy (IR) 394
- Inorganic tea, and organic tea cultivation 486
- Insect pests of tea
 - caterpillars
 - bunch caterpillar 253–255
 - looper caterpillar 247–250
 - oriental tea tortrix 246–247
 - smaller tea tortrix 245–246
 - tea leaf roller 252–253
 - tea tortrix 242–245
 - twig caterpillar 250–252
 - and disease management 496–500
 - live wood termites
 - Glyptotermes dilatatus* 217–218
 - Neotermes greeni* 216–217
 - overview 213–214
 - up-country 214–216
- nematodes
 - burrowing nematode 229–230
 - Hemicriconemoides kanayaensis* 230–231
 - root-feeding nematodes 222–223
 - root-knot nematode 223–224
 - root-knot nematode of mature tea 224–225
 - root-knot nematodes of young tea 225–226
 - root lesion nematodes 226–229
- nettle grub
 - A. recta* 258
 - blue-striped nettle grub 257–258

- fringed nettle grub 255–257
- gelatine grub 259
- large gelatine grub 259
- saddle-backed nettle grub 258
- tea flush worm 259–260
- occasional and minor pests
 - army worm 288–289
 - bag worm or faggot 289
 - cut worm 288
 - leaf miner 286–287
 - lobster caterpillar 284–286
 - red ant 287–288
 - red borer 279–280
 - red slug 286
 - root mealy bug 284
 - scale insects 282–284
 - tea aphids 280–282
 - white grub 278–279
- overview 201–206, 241–242
- scavenging termites
 - Ancistrotermes* sp. 222
 - Coptotermes ceylonicus* 219–220
 - Hospitalitermies monoceros* 220
 - Microcerotermis* sp. 221
 - Odontotermes* sp. 220–221
 - Pseudacanthotermes* sp. 222
- SHB beetle 211–213
- shot hole borers 207–211
- sucking pests
 - Kanzawa spider mite 276–277
 - lygus bug 263–264
 - mites 268
 - pink rust mite 274–275
 - purple mites 272–274
 - red spider mite 268–271
 - scarlet mite 271–272
 - tea jassid 264–266
 - tea mosquito bug 260–263
 - tea thrips 266–267
 - yellow mite/broad mite 275–276
- termites 213
- Instant tea 407–408
- Institutional partnerships, and
 - smallholders 526–527
- Integrated pest management (IPM)
 - biological control
 - allomones 313
 - avian control 316
 - bacteria 316
 - botanicals 310–311
 - kairomones 313
 - other predators and parasites 314–315
 - pheromones 312
 - semiochemicals 312
 - spiders 314
 - synomones 312
 - viruses 315–316
 - chemical control
 - case studies 317–325
 - at physiological level 317
 - cultural control
 - avoiding planting alternate hosts 307
 - bush sanitation 310
 - escape strategy 310
 - grafting 306
 - growing antagonists 307
 - growing trap crops 307–308
 - host plant resistance 305–306
 - plant nutrients 309
 - soil amendments 309
 - soil condition 308–309
 - detection methods
 - pest monitoring traps 303–304
 - population modelling 304–305
 - proper identification 304
 - satellite remote sensors and GIS 305
 - visual observations/sampling 303
 - ET and EI levels 302–303
 - Euwallacea fornicatus* Eichhoff 325–326
 - Glyptotermes dilatatus* Bugnion and Popof 326–327
 - mechanical control 305
 - overview 301–302
 - root lesion nematode *Pratylenchus loosi* Loof 327–328
 - in south India 325
- IPM. see integrated pest management (IPM)
- IR. see infrared spectroscopy (IR)
- Japan's positive list system 360
- Kairomones 313
- LC-MS. see liquid chromatography-mass spectrometry (LC-MS)
- Liquid chromatography-mass spectrometry (LC-MS) 390–392
- Livestock and animal husbandry 489
- Live wood termites
 - Glyptotermes dilatatus* 217–218
 - Neotermes greeni* 216–217
 - overview 213–214
 - up-country 214–216
- Manuring 490–493
- Microbes in tea cultivation
 - and biological control 147–148
 - mechanism of action 148–150
 - cellulose-degrading microbial
 - biofertilizers 144
 - for commercialization 153–155
 - microbial management 145–147
 - microbial pesticides 144–145
 - nitrogen-fixing microbial
 - biofertilizers 139–141
 - overview 135–137

- phosphate-solubilizing microbial
 - biofertilizers 141–142
- potash-solubilizing microbial
 - biofertilizers 142–143
- soil microbial inoculants 137–139
- tea pest management 150–153
- MRL setting initiatives 360–364
- Nematodes
 - burrowing nematode 229–230
 - Hemicirromoides kanayaensis* 230–231
 - root-feeding nematodes 222–223
 - root-knot nematode 223–224
 - root-knot nematode of mature tea 224–225
 - root-knot nematodes of young tea 225–226
 - root lesion nematodes 226–229
- Nettle grub
 - A. recta* 258
 - blue-striped nettle grub 257–258
 - fringed nettle grub 255–257
 - gelatine grub 259
 - large gelatine grub 259
 - saddle-backed nettle grub 258
 - tea flush worm 259–260
- Neuroprotective effects 439–440
- Nitrogen-fixing microbial biofertilizers 139–141
- NMR. see nuclear magnetic resonance spectroscopy (NMR)
- Nuclear magnetic resonance spectroscopy (NMR) 393
- Occasional and minor pests
 - army worm 288–289
 - bag worm or faggot 289
 - cut worm 288
 - leaf miner 286–287
 - lobster caterpillar 284–286
 - red ant 287–288
 - red borer 279–280
 - red slug 286
 - root mealy bug 284
 - scale insects 282–284
 - tea aphids 280–282
 - white grub 278–279
- Organic tea cultivation
 - conversion from conventional to 487
 - and inorganic tea 486
 - inspection and certification 504–505
 - maintenance of
 - biodynamic (BD) agriculture 493–496
 - botanicals 498
 - boundaries and buffers 488
 - cultural control 498–500
 - drains 488
 - insect pest and disease management 496–500
 - livestock and animal husbandry 489
 - manual workers 500–503
 - manuring 490–493
 - planting materials 489–490
 - soil organic carbon (SOC) 489
 - soil reaction 488–489
 - terraces 488
 - weed management 496
 - manufacturing practices 503
 - overview 485–486
 - possible contamination source 504
 - and site selection 486–487
 - storage and packing 503–504
 - transportation and shipment 504
- Overweight/obesity/type 2 diabetes
 - animal models 434–435
 - epidemiological studies 436
 - mechanistic considerations 436–438
 - randomized controlled trials 435–436
- Pesticide residues
 - extent of 349–352
 - food safety standards
 - brew factor and risk assessment 364–365
 - EU standards 358–360
 - Japan's positive list system 360
 - MRL setting initiatives 360–364
 - measuring 348–349
 - methods for detecting 352–354
 - advanced 354–357
 - overview 347–348
 - strategies for reducing 365–366
- Pest monitoring traps 303–304
- Phenolic compounds
 - analysis of 395–399
 - sugars 399–400
- Pheromones 312
- Phosphate-solubilizing microbial
 - biofertilizers 141–142
- Phytochemicals, in tea
 - bioactive compounds
 - alkaloids 385, 405
 - amino acids 386, 404
 - carbohydrates 385–386
 - polyphenols 382–385
 - tea saponins 386–387, 405
 - chlorophyll and carotenoids 404
 - chromatographic techniques
 - capillary electrophoresis (CE) 392
 - gas chromatography (GC) 392–393
 - gas chromatography–mass spectrometry (GC–MS) 392–393
 - high-performance liquid chromatography (HPLC) 390–392
 - high-performance thin-layer chromatography (HPTLC) 393
 - liquid chromatography–mass spectrometry (LC–MS) 390–392
 - colour compounds
 - carotenoids 389–390

- chlorophyll 389
- diversified tea products
 - instant tea 407–408
 - ready-to-drink tea 408
- elements in tea 405–407
- flavour compounds
 - lipids 389
 - volatile compounds 388–389
- overview 375–382
- phenolic compounds
 - analysis of 395–399
 - analysis of sugars 399–400
- spectroscopic techniques
 - atomic emission spectroscopy (AES)/atomic absorption spectroscopy (AAS) 394
 - infrared spectroscopy (IR) 394
 - nuclear magnetic resonance spectroscopy (NMR) 393
 - ultraviolet-visible (UV-Vis) spectroscopy 394
- volatile compounds
 - adsorptive column method 401
 - brewed extraction 401
 - direct organic solvent extraction 400
 - simultaneous distillation and extraction (SDE) 400
 - solid phase microextraction (SPME) 402–404
 - solvent-assisted flavour evaporation (SAFE) 401
 - steam distillation under reduced pressure (SDR) 401
- Planting, of tea
 - aftercare field operations
 - bending and pegging 64
 - centering 64
 - mulching and cover crops 61–63
 - training of young plants 63
 - climatic requirements
 - rainfall 54
 - relative humidity 55
 - sun light 55
 - temperature 54
 - wind 55
 - description 61
 - harvesting
 - bearing and pruning 77
 - frequency of 75–76
 - generation 73–74
 - leaf handling 79
 - manual (selective) 74
 - mechanical 77–78
 - non-selective 77
 - severity of 75
 - standards of 76–77
 - land preparation 56
 - overview 53–54
 - pruning
 - aftercare 70–71
 - preparation of tea bushes 70
 - styles of 68–69
 - tipping operations 71–72
 - replanting 79–80
 - shade trees and wind belts 65–67
 - site selection 55
 - soil and soil moisture 56–59
 - soil rehabilitation 80
 - spacing 59–60
- Potash-solubilizing microbial biofertilizers 142–143
- Ready-to-drink tea 408
- Root diseases
 - Armillaria* root rot 184–186
 - black root rot 184
 - brown root rot 183–184
 - charcoal root rot 184
 - red root rot 182–183
- Root lesion nematode *Pratylenchus loosi* Loof 327–328
- SAFE. see solvent-assisted flavour evaporation (SAFE)
- SDE. see simultaneous distillation and extraction (SDE)
- SDR. see steam distillation under reduced pressure (SDR)
- Self-help groups (SHGs)
 - and smallholders 524–525
- Semiochemicals 312
- SHB beetle 211–213
- SHGs. see self-help groups (SHGs)
- Shot hole borers 207–211
- Simultaneous distillation and extraction (SDE) 400
- Smallholders, in tea cultivation
 - good agricultural practices (GAP) 523–524
 - overview 521–522
 - problems facing 522–523
 - and processors 525–526
 - role of institutional partnerships 526–527
 - self-help groups (SHGs) 524–525
- SOC. see soil organic carbon (SOC)
- Soil amendments 309
- Soil condition 308–309
- Soil microbial inoculants 137–139
- Soil organic carbon (SOC) 489
- Soil reaction 488–489
- Solid phase microextraction (SPME) 402–404
- Solvent-assisted flavour evaporation (SAFE) 401
- Spectroscopic techniques
 - atomic emission spectroscopy (AES)/atomic absorption spectroscopy (AAS) 394
 - infrared spectroscopy (IR) 394

- nuclear magnetic resonance spectroscopy (NMR) 393
- ultraviolet-visible (UV-Vis) spectroscopy 394
- SPME. *see* solid phase microextraction (SPME)
- Steam distillation under reduced pressure (SDR) 401
- Stem diseases
 - cankers 178–180
 - wood rot 180–182
- Sucking pests
 - Kanzawa spider mite 276–277
 - lygus bug 263–264
 - mites 268
 - pink rust mite 274–275
 - purple mites 272–274
 - red spider mite 268–271
 - scarlet mite 271–272
 - tea jassid 264–266
 - tea mosquito bug 260–263
 - tea thrips 266–267
 - yellow mite/broad mite 275–276
- Synomones 312
- Tea cultivation
 - and climate change (*see* climate change, and tea cultivation)
 - and planting (*see* planting, of tea)
 - smallholders in
 - good agricultural practices (GAP) 523–524
 - overview 521–522
 - problems facing 522–523
 - and processors 525–526
 - role of institutional partnerships 526–527
 - self-help groups (SHGs) 524–525
- Tea genomics
 - dormancy 29
 - overview 21–22
 - progress of 24–25
 - qualitative trait locus (QTL)
 - identification 22–24
 - secondary metabolites 25–27
 - stress response 27–29
- Tea pest management 150–153
- Tea production, and climate change
 - CO₂ concentration 461
 - extreme climate events 462
 - modelling and temperature 460
 - pests and diseases 461–462
 - rainfall/monsoon 460–461
 - soil quality 462
 - solar radiation 462
- Tea quality, and climate change
 - CO₂ concentration 464
 - temperature and rainfall 463–464
- Termites 213
- Ultraviolet-visible (UV-Vis) spectroscopy 394
- UV-Vis. *see* ultraviolet-visible (UV-Vis) spectroscopy
- Volatile compounds 388–389
 - adsorptive column method 401
 - brewed extraction 401
 - direct organic solvent extraction 400
 - simultaneous distillation and extraction (SDE) 400
 - solid phase microextraction (SPME) 402–404
 - solvent-assisted flavour evaporation (SAFE) 401
 - steam distillation under reduced pressure (SDR) 401
- Weed management 496