Global tea science

Current status and future needs

Edited by Dr V. S. Sharma, formerly UPASI Tea Research Institute, India

Dr M. T. Kumudini Gunasekare, formerly Tea Research Institute, Sri Lanka
Contents

Series list xi
Acknowledgements xv
Introduction xvi

Part 1 Tea Breeding and Germplasm

1 Ensuring the genetic diversity of tea plants 3
   Jian-Qiang Ma and Liang Chen, Tea Research Institute of the Chinese Academy of Agricultural Sciences (TRI, CAAS), China
   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
   Xinchao Wang, Xinyuan Hao, Lu Wang and Yajun Yang, Tea Research Institute of the Chinese Academy of Agricultural Sciences (TRI, CAAS), China
   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
   Mainaak Mukhopadhyay, University of Kalyani, India; and Tapan Kumar Mondal, National Bureau of Plant Genetic Resources, India
   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

*M. A. Wijeratne, Tea Research Institute, Sri Lanka*

1. Introduction
2. Climatic requirements of tea
3. New planting of tea
4. Preparation of the planting hole
5. Planting of tea
6. Aftercare field operations
7. Establishment of shade trees and wind belts
8. Pruning
9. Harvesting of tea
10. Replanting
11. Soil rehabilitation
12. Future trends and conclusion
13. Where to look for further information
14. References

### 5 The effect of cultivation techniques on tea quality

*P. Okinda Owuor, Maseno University, Kenya*

1. Introduction
2. Chemical quality parameters of tea
3. Cultivars and black tea quality
4. Environmental factors
5. Altitude and temperatures
6. Agronomic inputs and tea quality
7. Conclusion
8. Where to look for further information
9. Acknowledgement
10. References

### 6 The role of arbuscular mycorrhizal fungi in tea cultivation

*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*

1. Introduction
2. AMF, tea and the tea rhizosphere
3. Development of AMF-based bioformulation for tea plantations
4. Plant growth promotion following inoculation with AMF consortia
5. AMF inoculation, tea growth and tea quality
6. Conclusion and future perspectives
7. Where to look for further information
8. Acknowledgements
9. References

### 7 The role of microbes in tea cultivation

*P. N. Bhattacharyya and S. R. Sarmah, Tocklai Tea Research Institute, India*

1. Introduction
2. Soil microbial inoculants as biofertilizers: an overview
Part 3 Plant Protection

8 Diseases affecting tea plants 171
G. D. Sinniah, Tea Research Institute, Sri Lanka
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
Nalini C. Gnanapragasam, Former Deputy Director (Research), Tea Research Institute, Sri Lanka; currently Agricultural Tea Consultant - Malwatte Valley Plantations PLC, Sri Lanka
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
Nalini C. Gnanapragasam, Former Deputy Director (Research), Tea Research Institute, Sri Lanka; currently Agricultural Tea Consultant - Malwatte Valley Plantations PLC, Sri Lanka
1 Introduction 241
2 Caterpillars and other seasonal pests 242
# Contents

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 301  
*Nalini C. Gnanapragasam, Former Deputy Director (Research), Tea Research Institute, Sri Lanka; currently Agricultural Tea Consultant - Malwatte Valley Plantations PLC, Sri Lanka*  
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 347  
*A. K. Barooah, Tocklai Tea Research Institute, India*  
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 375  
*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*  
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 427
Chung S. Yang, Rutgers University, USA
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 455
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
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 473
Thushari Lakmini Wijeratne, Tea Research Institute, Sri Lanka
1 Introduction 473
2 The environmental impact of tea cultivation 474
3 Making tea cultivation more sustainable 476
### Contents

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

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 in 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
© Burleigh Dodds Science Publishing Limited, 2018. All rights reserved.
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
Coctotermes ceylonicus 219–220
Hospitalitermems 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
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 El 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
nitrogen-fixing microbial biofertilizers 144
for commercialization 153–155
microbial management 145–147
microbial pesticides 144–145
vegetation management 144–145
nitrogen-fixing microbial biofertilizers 139–141
overview 135–137

© Burleigh Dodds Science Publishing Limited, 2018. All rights reserved.
Index

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
*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

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

flavour compounds
  lipids 389
  volatile compounds 388–389

over view 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 64
  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

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
- **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