

Edited by Sreeraj Gopi, Nimisha Pulikkal Sukumaran,
Joby Jacob, and Sabu Thomas

Natural Flavours, Fragrances, and Perfumes

Chemistry, Production, and Sensory Approach



Table of Contents

[Cover](#)

[Title Page](#)

[Copyright](#)

[Preface](#)

[Part I: Biodiversity](#)

[1 Natural Product Diversity and its Biomolecular Aspects in Flavors and Fragrances](#)

[1.1 Introduction](#)

[1.2 Genetic Resources and Plant Breeding](#)

[1.3 Agricultural Diversification](#)

[1.4 Conservation of Agrobiodiversity](#)

[1.5 Economically Important Natural Products Used in Flavors and Fragrances](#)

[1.6 Conclusion](#)

[Acknowledgment](#)

[Declaration of Interest](#)

[References](#)

[Part II: Commercial Biotechnology Pathways, and Their Applications to Industrial Sustainability](#)

[2 Biogenesis of Plant-Derived Flavor Compounds](#)

[2.1 Introduction](#)

[2.2 Primary and Secondary Flavor Compounds](#)

[2.3 Mechanistic Pathways of Flavor Formation](#)

[2.4 Conclusion](#)

[References](#)

3 A Sense of Design: Pathway Unravelling and Rational Metabolic Flow Switching for the Production of Novel Flavor Materials

3.1 Introduction

3.2 Elicitation of Plants

3.3 Transformation Within Cells

3.4 Metabolic Engineering

3.5 Plant Tissue Culture

3.6 Transgenic (Genetically Modified Organisms) Organisms

References

Part III: Flavor Technology

4 Flavor Technology and Flavor Delivering Systems

4.1 Introduction

4.2 Flavor Delivery Systems

4.3 Encapsulation Techniques

4.4 Future Perspectives

References

5 Flavor Signatures of Beverages and Confectionaries

5.1 Introduction

5.2 Classification of Flavor Compounds

5.3 Plant Parts as Flavoring Compounds

5.4 Flavor Signatures

5.5 Role of Flavor Compounds in Sensory Attributes

5.6 Conclusion

References

6 Flavor Biochemistry of Fermented Alcoholic Beverages

[6.1 Introduction](#)

[6.2 General Aspects of Alcohol Fermentation](#)

[6.3 General Aspects of Flavor](#)

[6.4 Flavor Biochemistry in Fermented Beverages](#)

[6.5 Conclusions](#)

[References](#)

[Part IV: Food Industry Ingredients](#)

[7 The Resinoids: Their Chemistry and Uses](#)

[7.1 Introduction](#)

[7.2 Benzoin Siam \(*Styrax tonkinensis craib ex hartwiss*\) and Benzoin Sumatra \(*Styrax benzoin*\)](#)

[7.3 Labdanum \(*Cistus ladaniferus*\)](#)

[7.4 Myrrh \(*Commiphora myrrha*\)](#)

[7.5 Conclusions](#)

[References](#)

[8 Seasoning, Herbs, and Spices](#)

[8.1 Introduction](#)

[8.2 Spices as Seasoning Ingredient](#)

[8.3 Herbs as Seasoning Ingredient](#)

[8.4 Seasoning Blends](#)

[8.5 Future Aspects](#)

[References](#)

[Part V: Regulations, Consumer Trends, and In Silico Biology](#)

[9 Regulatory Aspects for Flavor and Fragrance Materials](#)

[9.1 Introduction](#)

[9.2 Biosynthesis of Food Flavors](#)

[9.3 Safety Evaluation of Added Flavors by FDA](#)

[9.4 Conclusion](#)

[References](#)

[10 Sensory Science and its Perceptual Properties](#)

[10.1 Introduction](#)

[10.2 Sensorial Characteristics](#)

[10.3 Sensory Evaluation - Perception -
Acceptance of Foods](#)

[10.4 Sensory Control of Foods - Methodology](#)

[10.5 Conclusions](#)

[References](#)

[11 Challenges of Sensory Science: Retention and
Release](#)

[11.1 Introduction](#)

[11.2 Bottlenecks and Novel Insights of Sensory
Science](#)

[11.3 Sensorium Organs](#)

[11.4 Factors Affecting Flavor Retention and
Release](#)

[11.5 Future Prospects](#)

[References](#)

[12 Virtual Screening: An *In Silico* Approach to
Flavor Compounds](#)

[12.1 Introduction](#)

[12.2 Flavor Bioinformatics](#)

[12.3 Computational Strategies](#)

[12.4 Quality and Safety of Flavor Compounds](#)

[12.5 Conclusion](#)

[References](#)

[13 Endpoint: A Sensory Perception of Future](#)

[13.1 Introduction](#)

[13.2 Sensory Perception](#)

[13.3 Flavor Perception](#)

[13.4 Consumer Perception](#)

[13.5 Future of Flavors](#)

[13.6 Conclusion](#)

[References](#)

[Index](#)

[End User License Agreement](#)

List of Tables

Chapter 1

[Table 1.1 Economically important plants and their ingredients.](#)

[Table 1.2 Important aromatic plants and their bioactives.](#)

Chapter 2

[Table 2.1 Terpenoids and their examples used in flavor and fragrance industr...](#)

[Table 2.2 Flavor and Fragrance industry relevant phenolic compounds.](#)

Chapter 4

[Table 4.1 Different methods of flavor encapsulation \[18\].](#)

Chapter 5

[Table 5.1 Flavoring compounds and their application in confectionaries and b...](#)

[Table 5.2 Basic tastes and methods to reduce, complement, and heighten them....](#)

Chapter 7

[Table 7.1 Flavor and odor profile of some commercially important resinoids....](#)

[Table 7.2 Some important biological activities of commercially available res...](#)

Chapter 8

[Table 8.1 Ingredient list of different types of seasoning.](#)

Chapter 9

[Table 9.1 Table for permissible limits of various flavors.](#)

Chapter 10

[Table 10.1 Classification of sensorial characteristics/attributes/properties...](#)

[Table 10.2 Standards for training on the individual sensory characteristics....](#)

[Table 10.3 Sensory methods - sensory tests.](#)

List of Illustrations

Chapter 1

[Figure 1.1 A unified framework of using genomic resources for genomic breedi...](#)

Chapter 2

[Figure 2.1 Classification of flavors.](#)

[Figure 2.2 Examples of plant primary flavor-active metabolites with their st...](#)

[Figure 2.3 Types of fermentation and their use in food industries.](#)

[Figure 2.4 Classification of secondary metabolites with or without nitrogen ...](#)

[**Figure 2.5 Schematic representation of pathways responsible for biosynthesis...**](#)

[**Figure 2.6 Scheme of secondary metabolite pathways leading to flavor. MVA; m...**](#)

Chapter 3

[Figure 3.1 Commercially important metabolic pathways and examples of flavors...](#)

[**Figure 3.2 Lactone production from nonhydroxylated fatty acids. a\) Free fatt...**](#)

[**Figure 3.3 A network of transcription factors related to flavor compound met...**](#)

[Figure 3.4 Major tailoring enzymes and reactions in flavonoid biosynthesis....](#)

Chapter 5

[Figure 5.1 Three main categories of flavor substances used in industries wit...](#)

[Figure 5.2 Classification based on flavoring compounds.](#)

[Figure 5.3 Classification based on flavor generation.](#)

Chapter 6

[Figure 6.1 Overall reaction of alcohol fermentation.](#)

[Figure 6.2 Yeast growth behavior during alcohol fermentation.](#)

[Figure 6.3 Indication of the major types of papillae on the human tongue....](#)

[Figure 6.4 Interaction between grape compounds and yeast resulting in differ...](#)

[Figure 6.5 The biochemical pathway for ester synthesis and degradation.](#)

[Figure 6.6 The biochemical Ehrlich pathway for fusel alcohol synthesis.](#)

[Figure 6.7 The biochemical pathway for aldehyde metabolism, resulting in hig...](#)

Chapter 7

[Figure 7.1 The main classes of compounds present in asafoetida resinoid.](#)

[Figure 7.2 Characteristic compounds of galbanum resinoid. \(a\) Coumarin deriv...](#)

[Figure 7.3 Main volatile constituents of elemi.](#)

[Figure 7.4 Some constituents of styrax.](#)

[Figure 7.5 Main compounds of benzoin resinoids. \(a\) Characteristic compound ...](#)

[Figure 7.6 Characteristic compounds of labdanum resinoid.](#)

[Figure 7.7 Selected constituents of myrrh resinoid: fragrant furanosesquiter...](#)

Chapter 12

[Figure 12.1 Integrating multi-omics approaches for the study of flavor devel...](#)

[Figure 12.2 Schematic representation of biopeptide biosynthesis and database...](#)

[Figure 12.3 Steps involved in homology modeling.](#)

[Figure 12.4 Virtual screening and prediction of matrix.](#)

Natural Flavours, Fragrances, and Perfumes

**Chemistry, Production, and Sensory
Approach**

*Edited by Sreeraj Gopi, Nimisha Pulikkal Sukumaran, Joby
Jacob, and Sabu Thomas*

WILEY  **VCH**

Editors

Dr. Sreeraj Gopi

Chemical Faculty
Gdansk University of Technology
Gdansk
Poland
Overseas Expert Professor - Shanghai University
China

Mrs Nimisha Pulikkal Sukumaran

Aurea Biolabs (P) Ltd
R&D Center
Kolenchery
Cochin
682311 Kerala
India

Dr. Joby Jacob

Aurea Biolabs (P) Ltd
R&D Center
Kolenchery
Cochin
682311 Kerala
India

Prof. Sabu Thomas

Mahatma Gandhi University
Center for Nanoscience and Nanotechnology
Priyadarshini Hills
686-560 Kottayam, Kerala
India

Cover Image: © Caster/Shutterstock

All books published by **WILEY-VCH** are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <<http://dnb.d-nb.de>>.

© 2023 Wiley-VCH GmbH, Boschstraße 12, 69469 Weinheim, Germany

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Print ISBN: 978-3-527-34708-7

ePDF ISBN: 978-3-527-82479-3

ePub ISBN: 978-3-527-82480-9

oBook ISBN: 978-3-527-82481-6

Preface

It has been a while since a book was put together to address the natural flavors in industrial formulations, including concise treatments of the relation between sophisticated methods and better comprehension of consumer perception and behavior using a multidisciplinary metabolic engineering methodology by connecting with fields. It appears, however, that a gap has arisen between the new advances in basic information and the direct application to product situations, with a critical requirement for scientific data. Besides, flavor innovation is a developing powerful field, which keeps on expanding its applications from its foundations in food and beverage to incorporate categories as different as personal care products and household products. But, consumer perceptions of naturalness and perceived healthiness influence their product choices and increase the preference for products labeled as natural. Consequently, keeping in mind the negative health perceptions brought about by many factors, including artificial flavors, ingredient unfamiliarity, advancements in processing, and so on, researchers all over the world have recently focused on flavors from natural resources with much success.

The idea of compiling the book *Natural Flavors, Fragrances, and Perfumes: Chemistry, Production, and Sensory Approach* took seed in mid-2018. The urge to foster such a book originated from the perspective of growing in this area, giving special emphasis on fundamental and applied research findings, and more persuasively in a food manufacturing business, to enhance product quality, and extend the shelf life of the products and improve process efficiency. This book is a systematic,

complete, sequential compilation of information about the engineering of flavors and flavor products in the area of its application to provide insights to help guide development and in commercial strategy. Indeed, the goal of this book is to bring together some of the core knowledge in the field to provide a practical and wide-ranging guide for molecular biologists, new product researchers, and scientists involved in the commercial development of natural flavors and flavor-related compounds, and their use in applications as varied as pharmaceuticals, nutraceuticals, or fragrances.

This book is divided into 5 parts, including 13 chapters encompassing from natural product diversity and synthesis of flavor compounds to all different kinds of applications in the food and fragrance industries. It begins with a part devoted to the natural product diversity and its biomolecular aspects. [Chapters 2](#) and [3](#) present advances in the strategies of metabolic pathway engineering and the biogenesis of plant-derived aroma compounds. The next part of the book ([Chapters 4–6](#)) focuses on flavor technology and the different kinds of flavor-delivering systems, signatures, and biochemistry of beverages. [Chapters 7](#) and [8](#) are oriented to specific examples and applications of seasonings, herbs, spices, and resinoids to get a better understanding of their chemistry and uses. The last chapters are focused on regulatory aspects, sensory science and its challenges, advances in *in silico* approaches, and sensory perceptions.

A book like this is impossible without the support and effort of the contributors who have taken the time to submit their manuscripts during the pandemic period. Our editors wish to thank the authors who have generously contributed material to this book. They are experts in their fields and have provided valuable information and insights into the naturally derived flavors. The contributors include Valsaraj T.V.; Akhila Nair; Józef T. Haponiuk; Sumith K.; Anjali Anil;

Neha Naijo Areekal; Sneha George; Irene Mary Peter; Roshin Thankachan, Maurício Bonatto Machado de Castilhos; Ana Paula Garrido de Queiroga; Lia Lúcia Sabino; Jorge Roberto dos Santos Júnior; Jorge Alejandro Santiago-Urbina; Hipócrates Nolasco-Cancino; Francisco Ruíz-Terán; Vanildo Luiz Del Bianchi; Daniel Jan Strub; Maria Strub; Nicolas Baldovini; Vaishak Ramachandran; Anirudh Jayakumar; Constantina Tzia; Virginia Giannou; Tryfon Kekes; Charikleia Chranioti; Maria Katsouli; Nirosha Pulikkal; and Dhanesh Haridas.

25 August 2022

*Sreeraj Gopi
Nimisha P. Sukumaran
Joby Jacob
Sabu Thomas
Kochi, India*

Part I

Biodiversity

1

Natural Product Diversity and its Biomolecular Aspects in Flavors and Fragrances

*Themanamveedu Valsaraj, Akhila Nair, and Joby Jacob
Aurea Biolabs (P) Ltd., R&D Centre, Kolenchery, Cochin,
Kerala, 682311, India*

1.1 Introduction

In pharmaceutical, food, cosmetic, and nutraceutical industries, flavors and fragrances play a vital role. The natural selection method or processes facilitate unique as well as wide chemical diversity with optimal interactions with other biological macromolecules. Moreover, since a millennium, it is observed that the introduction of continental and conventional selective breeding efforts has resulted in land race, elite cultivars that could not only adapt to globally diverse habitats but also ensure vivid quality and productivity in flavors and fragrances worldwide. However, unraveling the genomic basis of these vivid adaptations remains indecipherable. For example, the world's oldest and most popular caffeine-containing beverage, the tea, comes along with immense medicinal, economic, and cultural virtues. Constant research will definitely pave way for a diverse metabolic, functional, and genomic refinement for the evaluation of their biosynthetic pathways [1]. Although it is well recognized that the differential accumulation of the three major characteristic constituents in tea tree leaves largely determines the quality of tea, little genomic information is currently available. Sequencing of the tea tree genome would facilitate to uncover the molecular mechanisms underlying secondary metabolic biosynthesis

with the promise to improve breeding efficiency and thus develop better tea cultivars with even higher quality. The development of tea clones with more desirable quality traits and enhanced stress resistance becomes a necessity. Strategizing such crop improvement procedures based on miRNAs requires a detailed understanding of the miRNA-mRNA modules associated with stress tolerance and quality in tea plants [2].

Biosynthesis of aroma compounds involves metabolic pathways in which the main precursors are fatty acids and amino acids, and the main products are aldehydes, alcohols, and esters. Some enzymes are crucial in the production of volatile compounds, such as lipoxygenase, alcohol dehydrogenase, and alcohol acyltransferase. Composition and concentration of volatiles in apples may be altered by pre- and postharvest factors that cause a decline in apple flavor [3]. Among the volatile aroma compounds produced by ripe apples, esters account for the majority. For example, among the volatile aroma compounds of Golden Delicious and Starking Delicious, esters account for 80% [4]. This chapter discusses the genetic resources and plant breeding, agricultural diversity, conservation of agrobiodiversity, and the economically useful natural products used as flavors and fragrances.

1.2 Genetic Resources and Plant Breeding

From time immemorial, the breeding and domestication of plant varieties and/or species for flavor, aroma, and other characteristics have been a constant and ongoing process. Novel heterogeneity in concentration and combination of secondary metabolites has been a constant source to develop new varieties of flavors and fragrances. These variations in the composition of secondary metabolites are affected by human preferences and domestication in flavors and aromas

[5]. Moreover, the need for a higher nutrition crop or fruit variety in terms of sustainable agriculture has put into limelight the genomic breeding approaches inclusive of marker-assisted selection, backcrossing, haplotype breeding, and genomic prediction methods in synergy with artificial intelligence and machine learning to increase the speed of these breeding approaches. [Figure 1.1](#) depicts an example of the use of an integrated framework of genomic resources [7].

1.3 Agricultural Diversification

Globally, in an agricultural system, aromatic plants are those with aromatic compounds. These aromatic plants synthesize secondary metabolites to produce essential oils, which provide relief from biotic and environmental stress. In addition, these essential oils are used in diverse applications like flavors, perfumes, and fragrance, which will provide economic returns to farmers and manufacturing industries. The increasing interest of research scholars worldwide encourages agricultural activities like proper land utilization as well as focuses on economic returns for aromatic crops. The ecological applications of these aromatic plants in agricultural systems lie in soil erosion control, carbon sequestration, phytoremediation, utilization of low-quality water, pest and disease management, and augmentation of soil properties [8]. The sensory evaluation or validation of spices depends on dominant attributes like color, aroma, and pungency, which is heavily influenced by the varieties, primary processing cultivation, and the processed products.

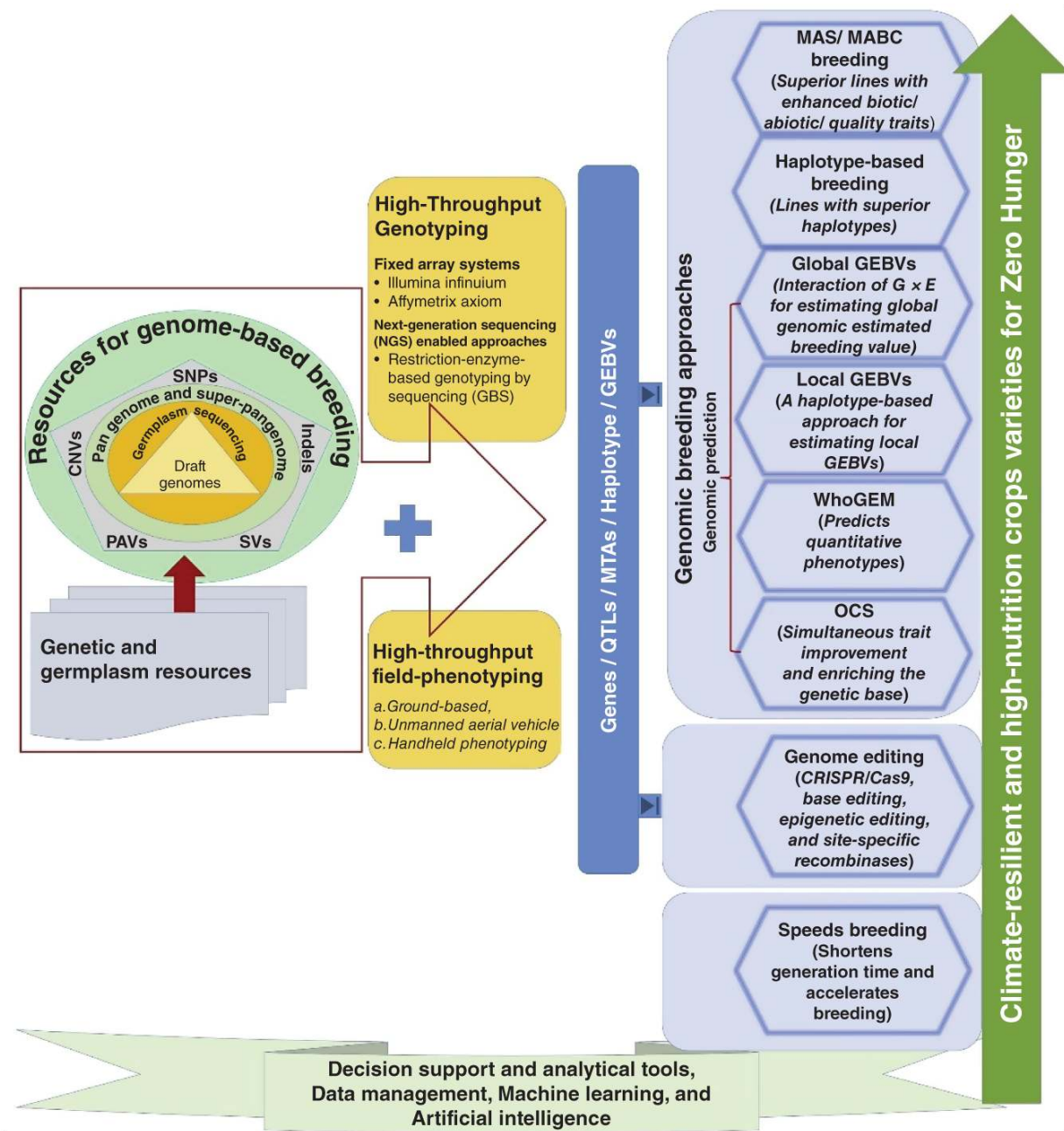


Figure 1.1 A unified framework of using genomic resources for genomic breeding to tailor climate resilient and high nutrition crops.

Source: Adapted from Ashry et al. [6].

1.4 Conservation of Agrobiodiversity

The natural product diversity witness difficulties at economic level due to denial of traditional collective seed ownership, make people helpless to grow, harvest, and channel sufficient surplus food. There are many internationally acclaimed reciprocated responses that work in favor of the intellectual property law of farmers. Furthermore, the United States of America have designed vivid grassroot agricultural and biodiverse conservation projects to regulate the open pollinated seeds within fraternities of similar interest. This project involves exploration of the functions of pollinated seeds and focuses on various other strategies for agricultural biodiversity conservation. There are research projects that collectively disseminate and document open-pollinated seed around Appalachian Mountains and Ozark highlands of southeastern United States. The research methods involve an anthropology team who can conduct ethnographic interviews and make participant observation that cover the growing and sharing of seed varieties with local farmers, seed savers, gardeners, and activists with a definite aim of constructing more integrated, sustainable, and sovereign local food systems.

1.4.1 Strategies for Conservation of Medicinal Plants

The conservation strategies of near-to-extinct species of medicinal and food or aroma importance can be determined through social and scientific actions. The strategies for conservation of medicinal plants to be used for vivid purposes can be classified into (i) the importance of genebanks, (ii) molecular-based phylogenetics, and (iii) chemosystematics [\[9\]](#).

1.4.1.1 Importance of Genebanks

To compensate the emergent loss of genetic diversity in medicinal crops, the establishment and maintenance of large *ex situ* plant genetic resources (PGRs) was started where

systemic breeding was developed by using genetically uniform cultivars to substitute traditional land races around the world. The seeds stocked in genebanks were considered as vital due to the fact it gave an insight of the historical background of the agriculture [10]. To illustrate, *Elettaria cardamomum*, which is an economically important crop, faces limitation in its genomic analysis because of the limitation of inefficient nucleic acid extraction due to its high polysaccharide and polyphenolic content. Therefore, genebanks provide an extraction protocol for nucleic acids that help to develop genetic markers for cardamom, perform gene expression, clone cardamom genes, analyze small RNAs, and clone cardamom-infecting viral genes [11].

1.4.2 Molecule-Based Phylogenetics

Cryptic diversity is often not recognized due to the incapability of recognizing the distinguishable morphological traits and because of inability to quantify the chemical communication systems. For certain plants or animals, species-level taxonomy is obstructed because of its distortion upon preservation and morphological plasticity. The morphological characteristics to differentiate likely related species using these methods become difficult, but recent advances in morphological characteristic-based studies imply several differences in the phenotypes. The revisions in taxonomic as well as molecular-based phylogenetic studies have proved to be promising to garner information related to large species groups with different genera [12].

1.4.3 Metabolomic-Based Phylogeny or Chemosystematics

The initial part of the last century witnessed the evolution of metabolomics-based phylogeny or chemosystematics that eventually gained its popularity in the 1970s [13]. However, these studies centered on the intrafamily classification at the species level as well as the measurement of particular

components of single biochemical families, especially alkaloids, in accordance with the technologies of that period. For example, the chemical systematics of the family Rutaceae and the order Rurales received immense research attention. The authenticity of chemosystematic classification was proved by comparison with the phylogeny determined by molecular polymorphism analyses.

1.5 Economically Important Natural Products Used in Flavors and Fragrances

The economically most important plants serving the purpose of flavors and fragrances are cardamom, cinnamon, cocoa, fenugreek, marigold, nutmeg, vanilla, paprika, rosemary, davana oil, olibanum carterii/serrata, lavender, vetiver, and so on ([Tables 1.1](#) and [1.2](#))

Table 1.1 Economically important plants and their ingredients.

Plant source	Active ingredients	Economic importance
Cardamom [14]	1,8-cineole, α -pinene, α -terpineol, linalool, linalyl acetate and nerolidol, and the ester constituent α -terpinyl acetate	Antioxidant, antimicrobial, antibacterial, anti-inflammatory
Cinnamon [15]	Cinnamaldehyde, trans-cinnamic acid, <i>o</i> -methoxycinnamaldehyde, eugenol, and monoterpenoids	Antioxidant, anti-inflammatory, antidiabetic, antimicrobial, anticancer, lipid-lowering, and cardiovascular-disease-lowering compound
Cocoa [16]	Theobromine, serotonin, anandamide, phenylethylamine	Antioxidation, anticancer, antimicrobial, anti-inflammation, anti-diabetes, cardioprotective, physical improvement, antiphotaging, antidepression, and blood glucose regulation

Plant source	Active ingredients	Economic importance
Fenugreek [17]	Carbohydrates, proteins, lipids, alkaloids, flavonoids, fibers, saponins, steroidal saponins	Hypocholesterolemia, lactation aid, antibacterial, gastric stimulant, for anorexia, antidiabetic agent, galactagogue, hepatoprotective effect, and anticancer
Marigold [18]	Carotenoids, flavonoids, saponins, sterols, phenolic acids	Anti-inflammatory, anti-edematous activity, antioxidant, antibacterial and antifungal activity, immunostimulant activity, genotoxic and antigen-toxic activity, spasmogenic and spasmolytic activity, hepatoprotective activity
Nutmeg [19]	Terpenes (α -pinene, <i>p</i> -cymene, sabinene, camphene, myrcene, and γ -terpinene), terpene derivatives (terpinol, geraniol, and linalool), and phenylpropanes	Antioxidant activity, immuno-modulatory and radioprotective activities, anti-carcinogenic and hepatoprotective activity, anti-inflammatory activity, antimicrobial activity

spices

- ajwain [134](#)
- asafoetida [134](#)-135
- black pepper [135](#)
- celery seed [135](#)
- chili pepper [135](#)-136
- cinnamon [136](#)
- clove [136](#)
- coriander [136](#)-137
- cumin [137](#)
- fennel [137](#)
- fenugreek [137](#)
- garlic [138](#)
- ginger [138](#)
- green cardamom [138](#)
- nutmeg and mace [139](#)
- onion [139](#)
- star anise [139](#)
- turmeric [140](#)
- spray chilling [67](#), [69](#)
- spray drying [67](#)-69
- star anise [139](#)
- stem cell growth factor receptor (SCFR) [195](#)
- styrax [122](#)-124
- Syzyium aromaticum* [136](#)

t

tactile [11](#), [73](#), [95](#), [166](#), [167](#), [175-177](#), [196](#)

Tagetes [10](#)

tailored enzymes [54-55](#)

taste enhancer [225](#), [228](#)

taste receptors [25](#), [65](#), [172](#), [212-213](#), [218](#), [226](#), [228](#)

taste types [207](#)

terpenoids [33-34](#), [38](#), [39](#), [117](#), [135](#), [136](#), [154](#)

texture of food [134](#), [175](#)

thyme [13](#), [141-142](#)

Thymus vulgaris [141-142](#)

toxicological concern (TTC) [150](#)

Trachyspermum ammi [134](#)

transcription factor (TF) [54](#)

transgenic organisms [58](#)

tricarboxylic acid (TCA) cycle [27](#), [35](#), [39](#)

Trigonella foenum graecum [10](#), [137](#)

turmeric [140](#)

u

umami taste [30](#), [35](#), [96](#), [142](#), [197](#), [212](#), [213](#), [231](#)

US food supply [150](#), [154](#)

v

vagus nerve [96](#), [197](#)

Vanilla planifolia [11](#)
Vanilla planifolia vanillin synthase (VpVAN) [12](#)
Vetiveria zizanioides [15](#)
virtual screening tools [214](#)
 docking setups [216](#)-217
 model validation [215](#)-216
 quantitative structure-activity relationship [215](#)
visual perception [168](#)
vitamins [29](#), [137](#)
Vitis vinifera [100](#)

W

wines [98](#)
 carbonyl compounds [103](#)-105
 esters [99](#)-103
 flavor precursors [99](#)
 higher alcohols [101](#)-103
 Mezcal [105](#)-108
 oak compounds [104](#)-105
wine sensory feature [99](#)

X

xylooligosaccharides (XOS) [81](#)

Z

Zingiber officinale [138](#)